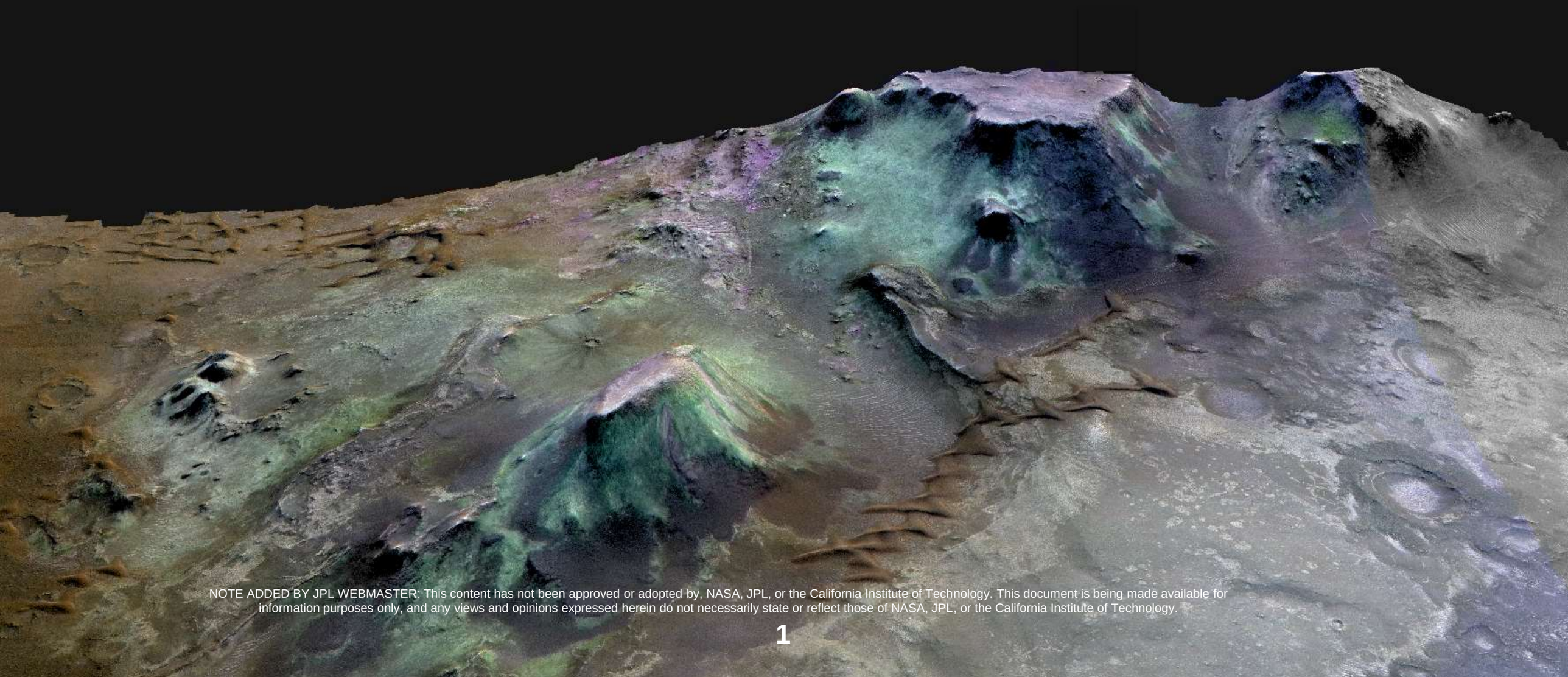
An Ancient Crustal Stratigraphy in the Nili Fossae Troug Clays, Carbonates, Impacts and Volcanics

K. Cannon, J. Mustard, G. Osinski, L. Tornabene, S. Parman, E. Amador, A. Brown, C. Viviano-Beck, B. Ehlmann, H. Sapers, A. Pontefract, D. Des Marais, N. Mangold, S. Wiseman



The Nili Fossae Trough is **ideally suited** for the Mars 2020 mission profile of **geology**, **biosignatures** and **caching:**

Multiple **types** of habitable environment: (layered clay-rich deposits, hydrothermal system).

Strongly relevant to life: excavation of possible **subsurface biosphere** and biomarker preservation in quenched impactites.

Diverse secondary mineralogy including **carbonate**, **Fe/Mg clays**, **Al clays.**

Cached samples will include: Altered and unaltered **mid-Noachian crust**, **carbonates**, in place Syrtis Major **volcanics**.

Both Noachian and Hesperian units are located **within the landing ellipse**.

Nili Fossae

Syrtis Major

Isidis Basin

150 km

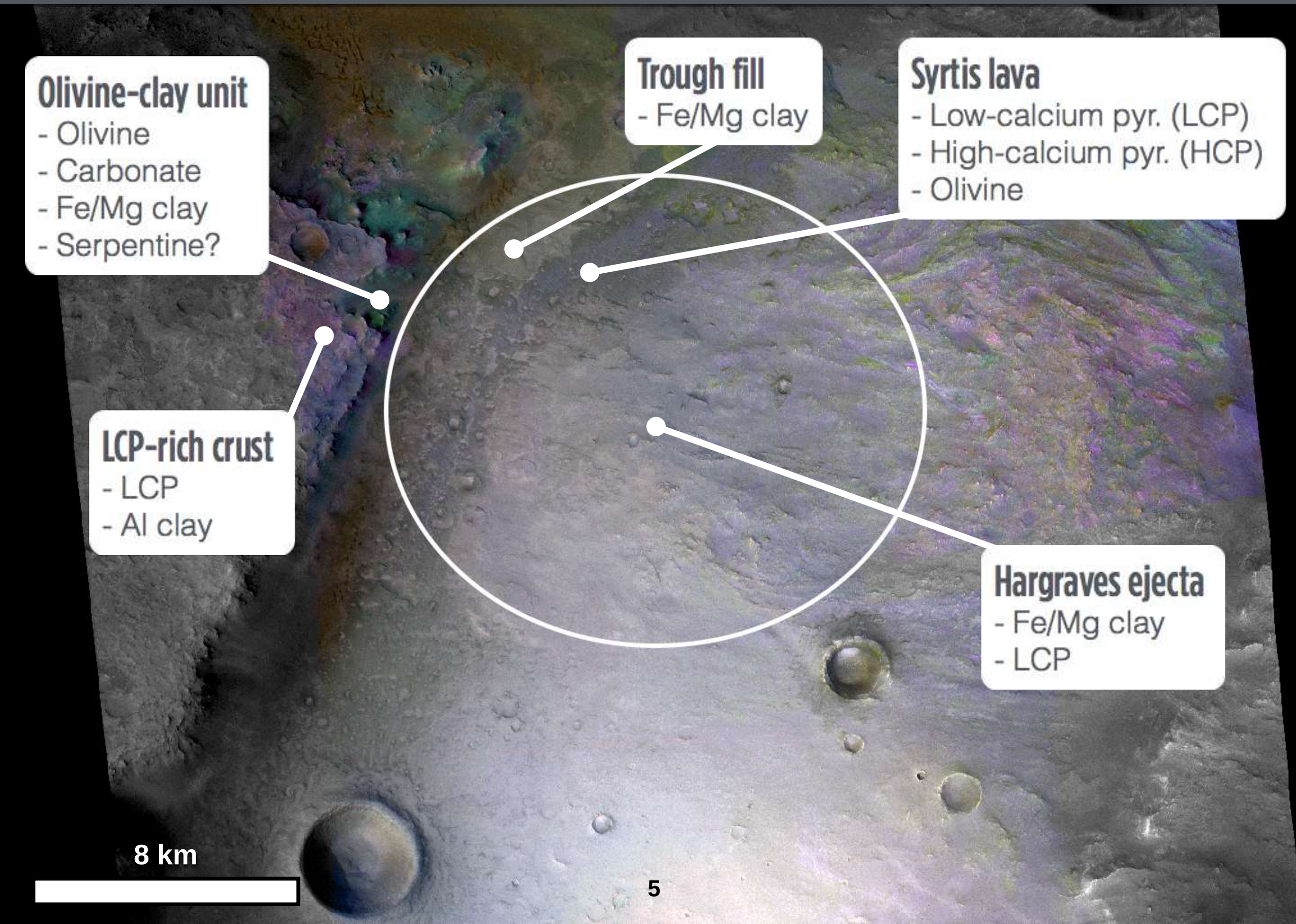
Trough

Re-entrant

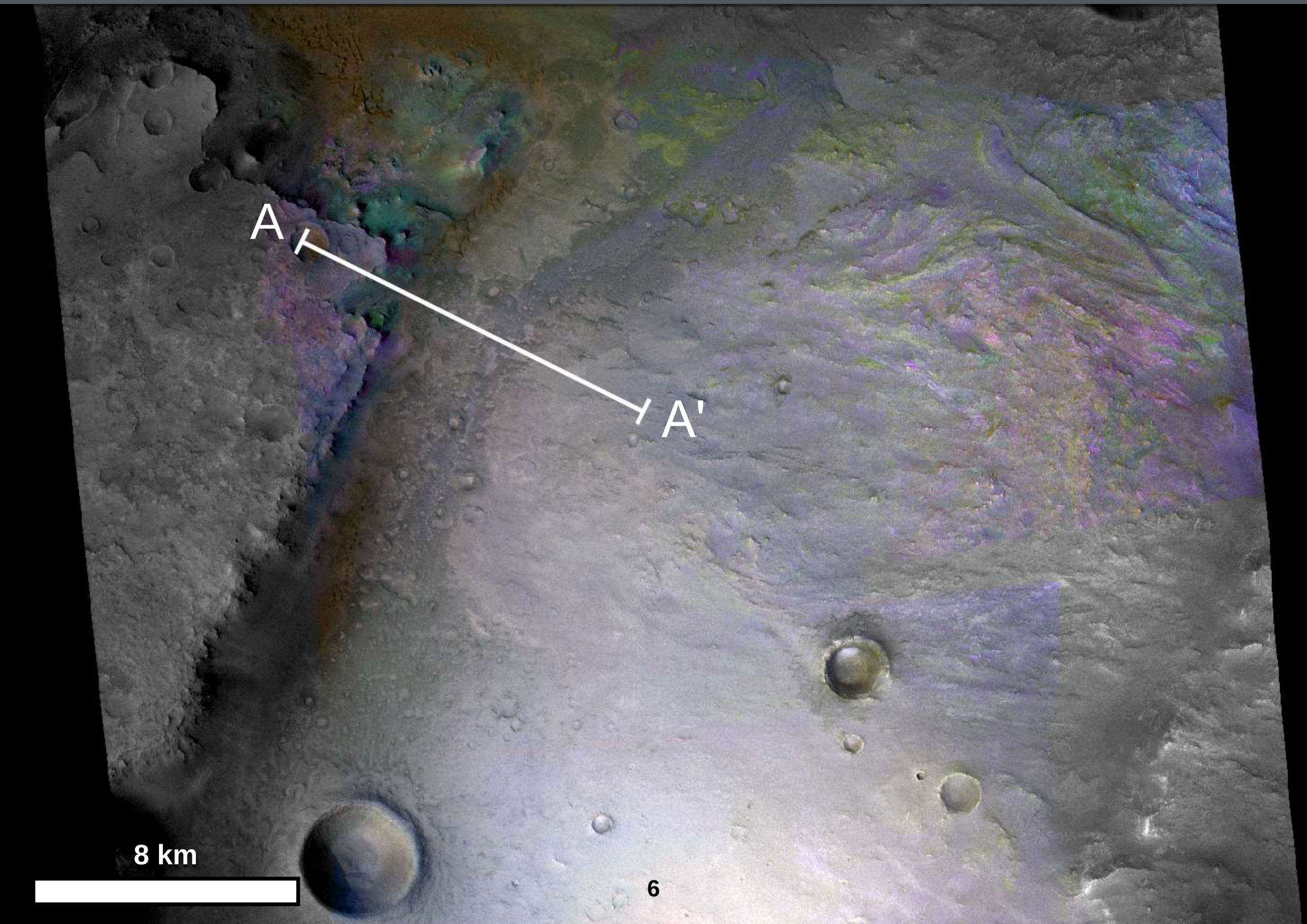
Hargraves Crater

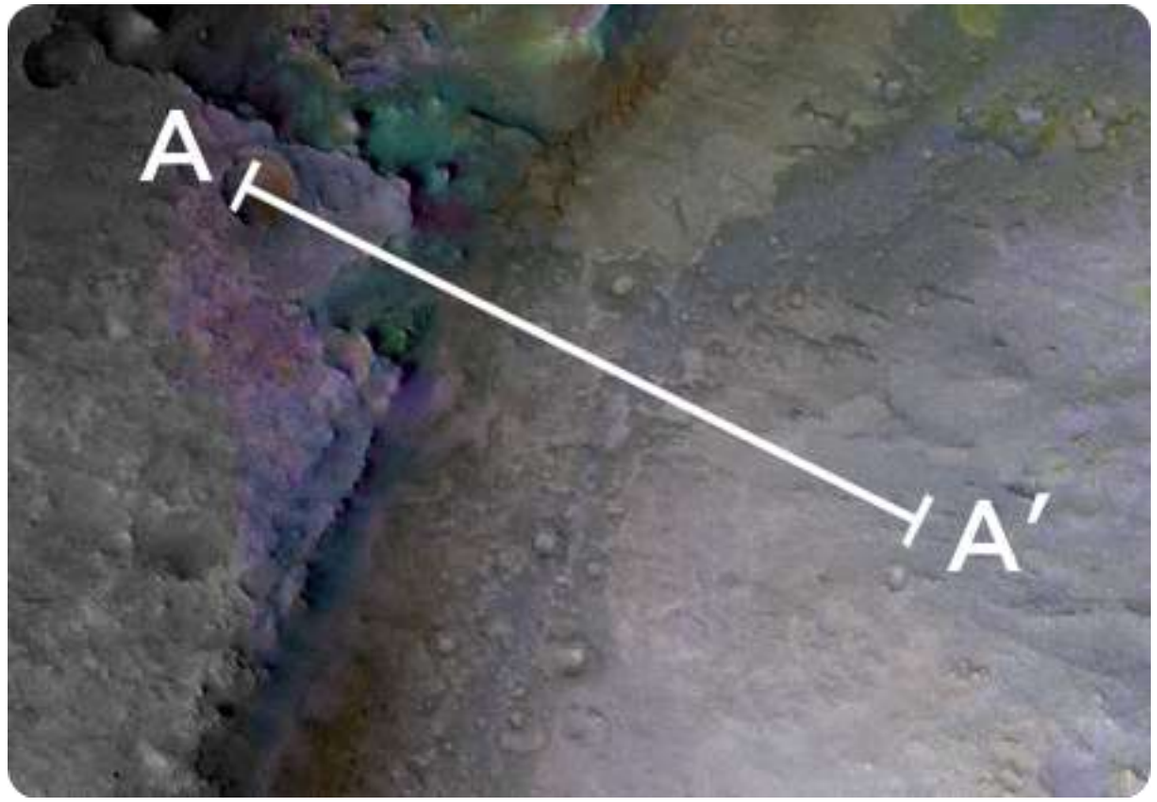
30 km

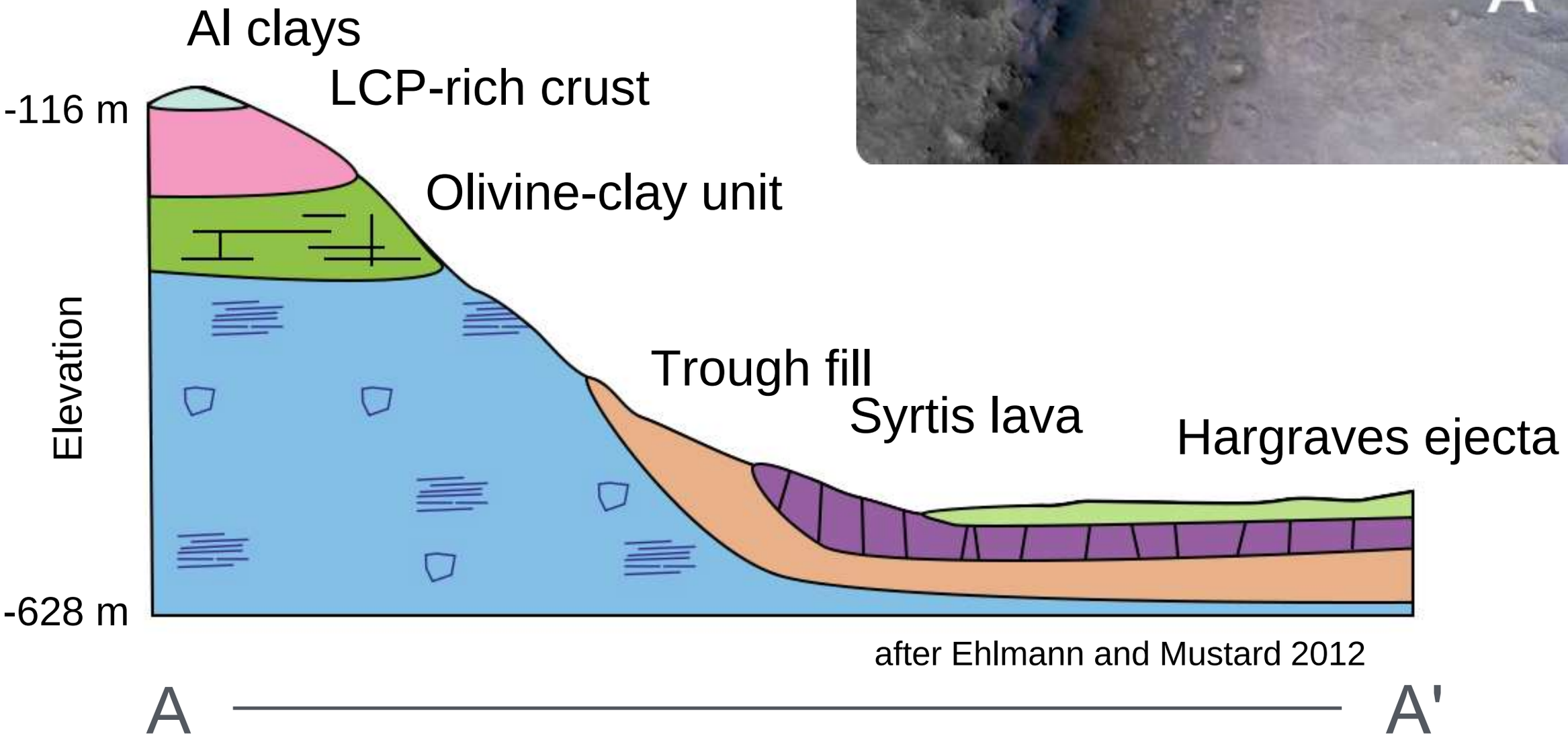
RED: 2380 nm, GREEN: 1800 nm, BLUE: 1150 nm



RED: 2380 nm, GREEN: 1800 nm, BLUE: 1150 nm



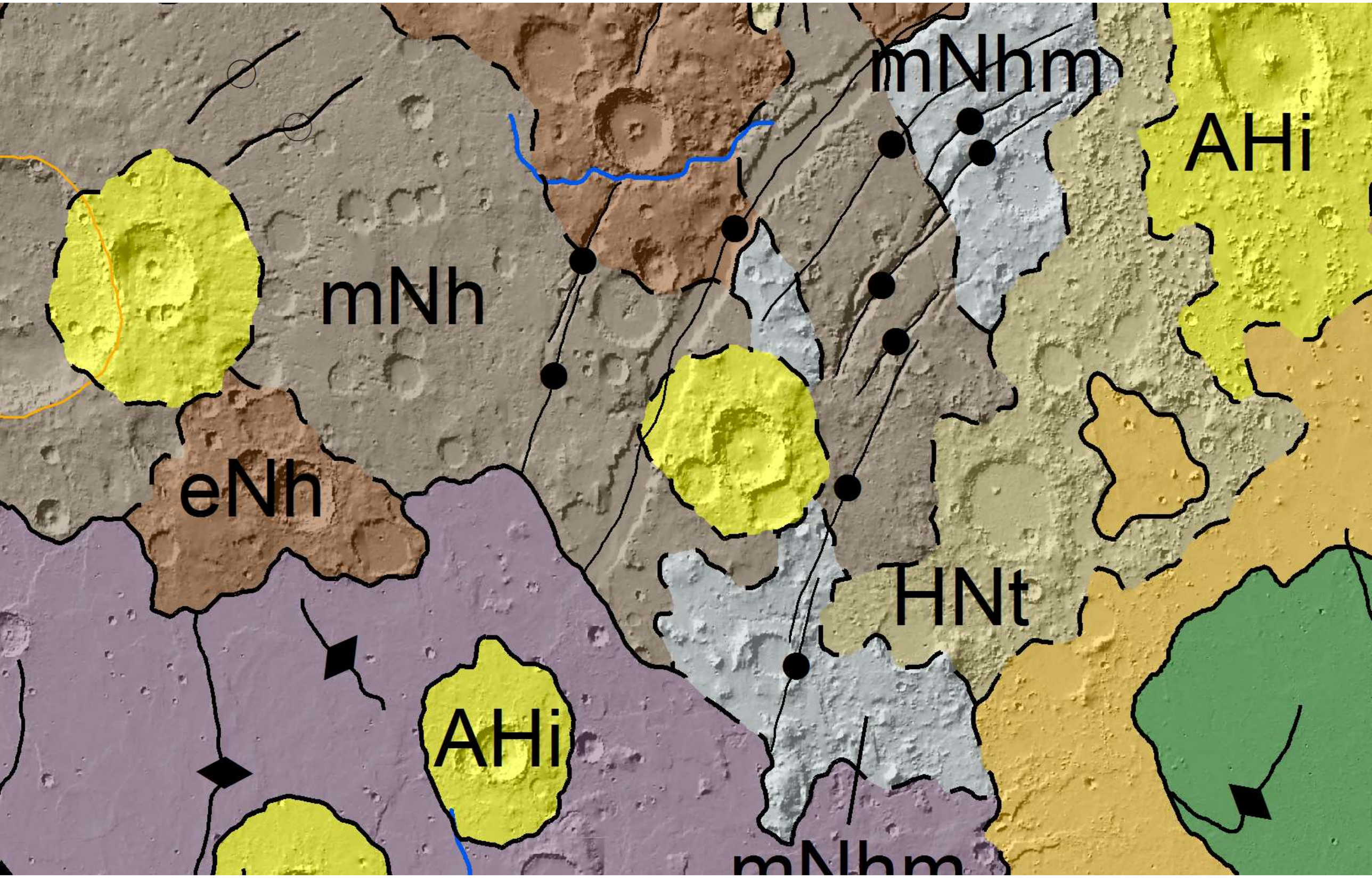

A
A′


Al clays
LCP-rich crust
-116 m
Olivine-clay unit
Elevation
Trough fill
Syrtis lava
Hargraves ejecta
-628 m
after Ehlmann and Mustard 2012
A
A'

In-ellipse science

8 km

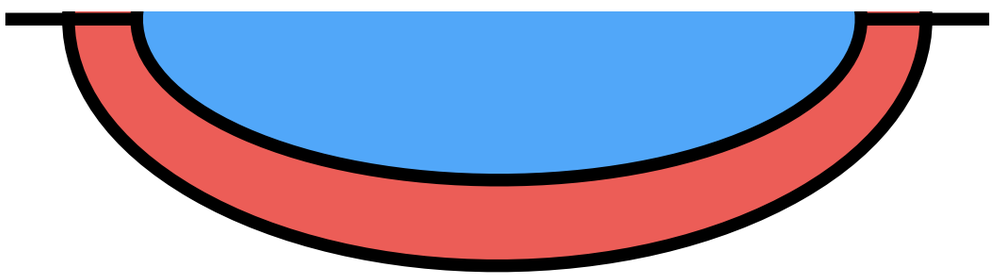
from Tanaka et al. 2014



Hargraves drills deep into No

D_{tc} ~ 28 km
(Holsapple 1993)

Hargraves

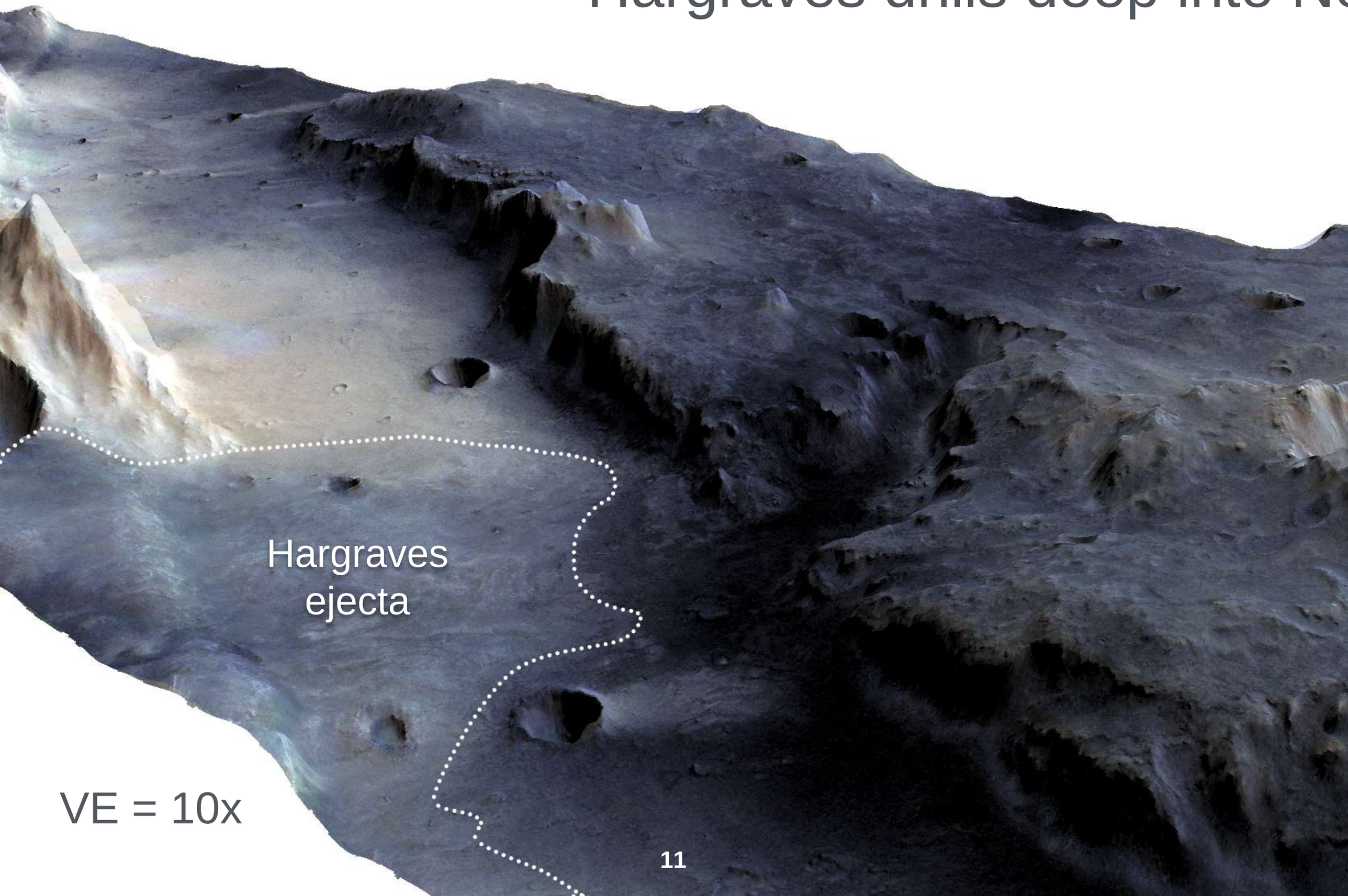


D_e ~3 km
Continuous ejecta

D_e ~7.2 km
Melt pools

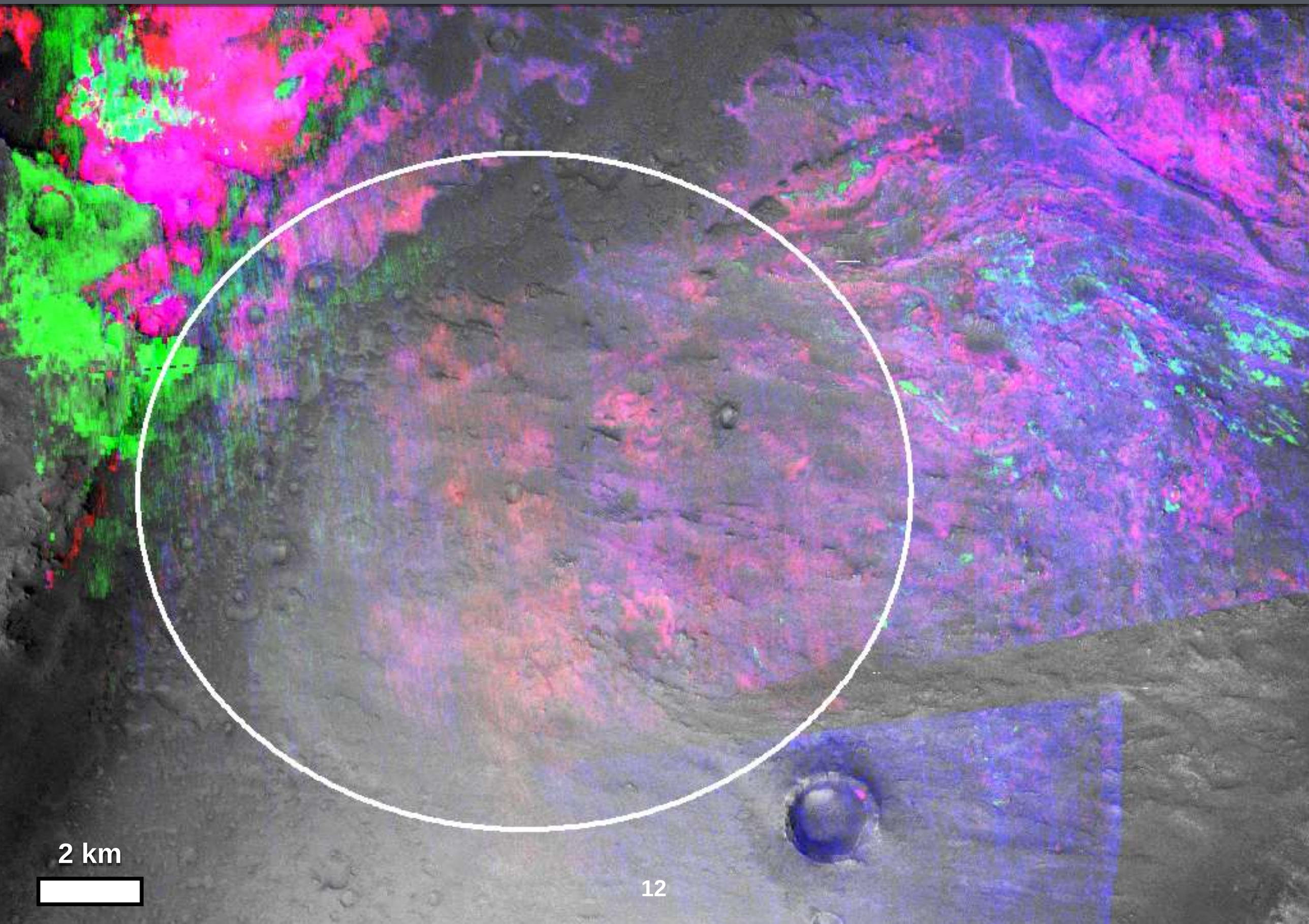
(Osinski et al. 2011)

Hargraves drills deep into No



VE = 10x

RED: D2300, GREEN: LCPINDEX2, BLUE: BD1900



RED: D2300, GREEN: LCPINDEX2, BLUE: BD1900

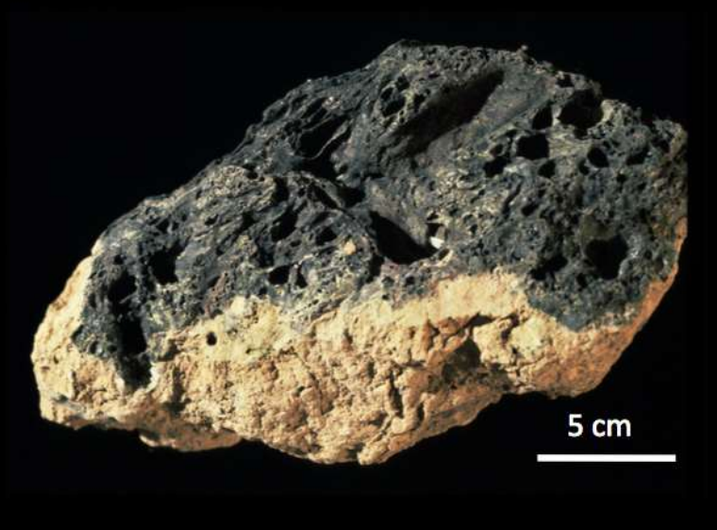
2 km

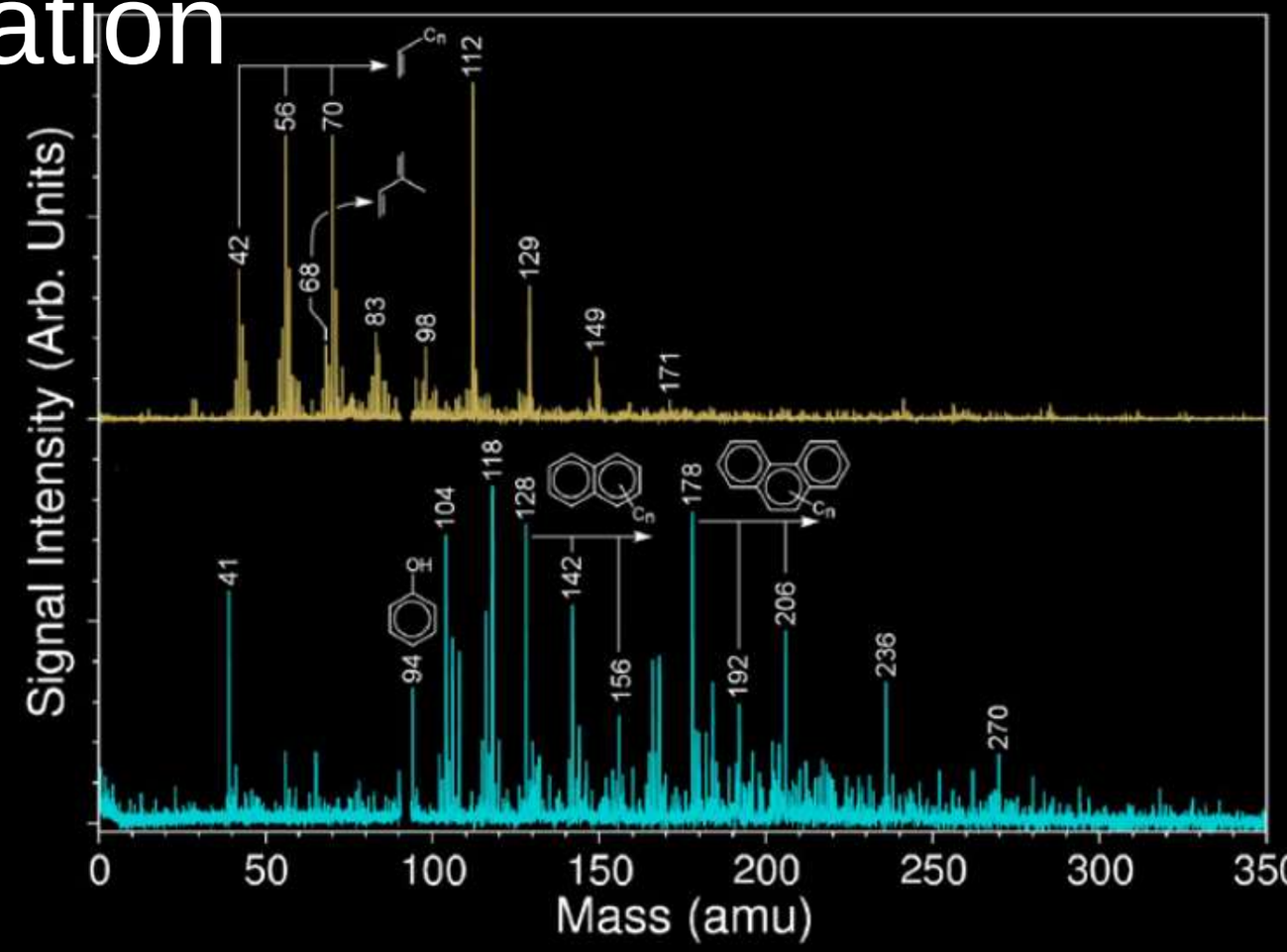
RED: D2300, GREEN: LCPINDEX2, BLUE: BD1900

LCP-rich rock

2 km

Biosignature preservation

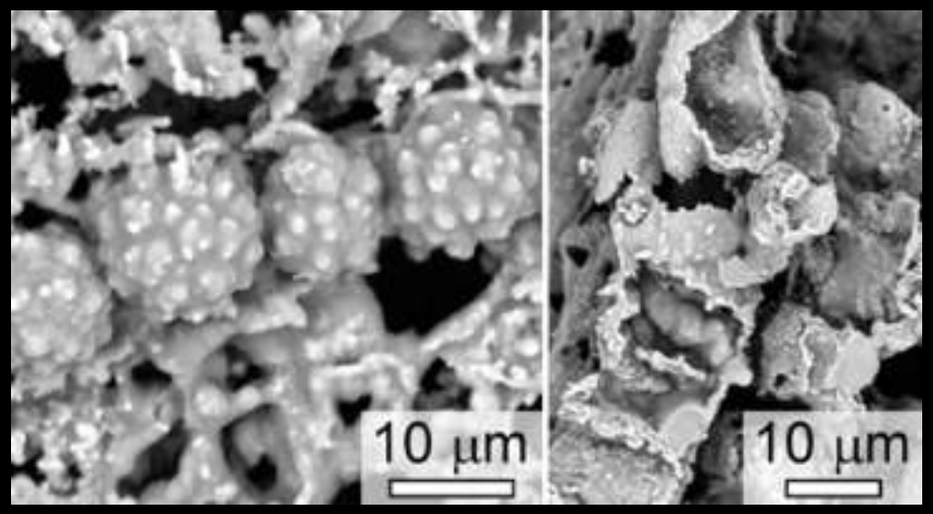




Quenched impact breccias can provide *exceptional biosignature preservation*, including:

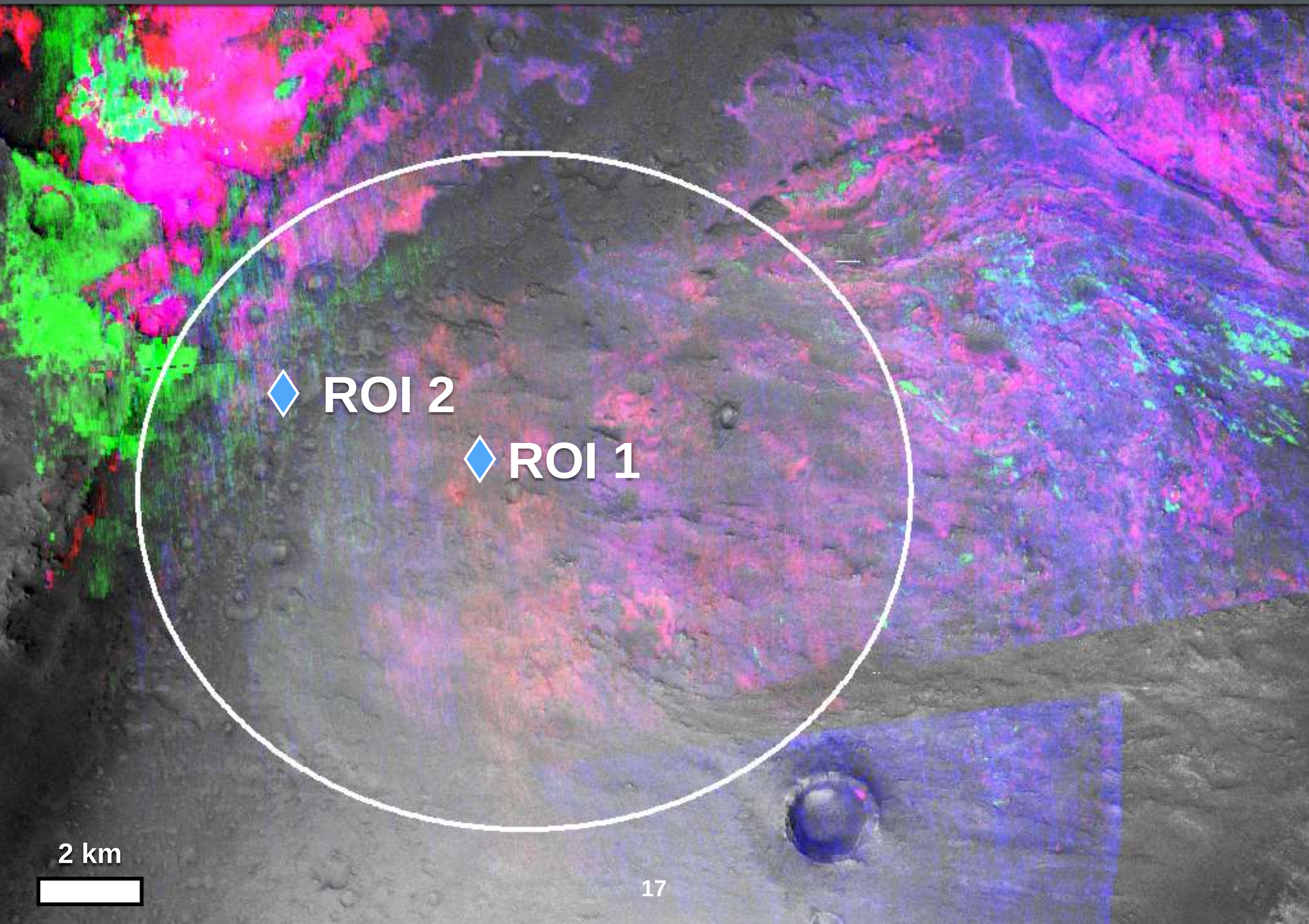
- Complex organic molecules
- Macrofossils

Both encased in 9.2 Ma impact glass from Argentina
(Schultz et al. 2014)



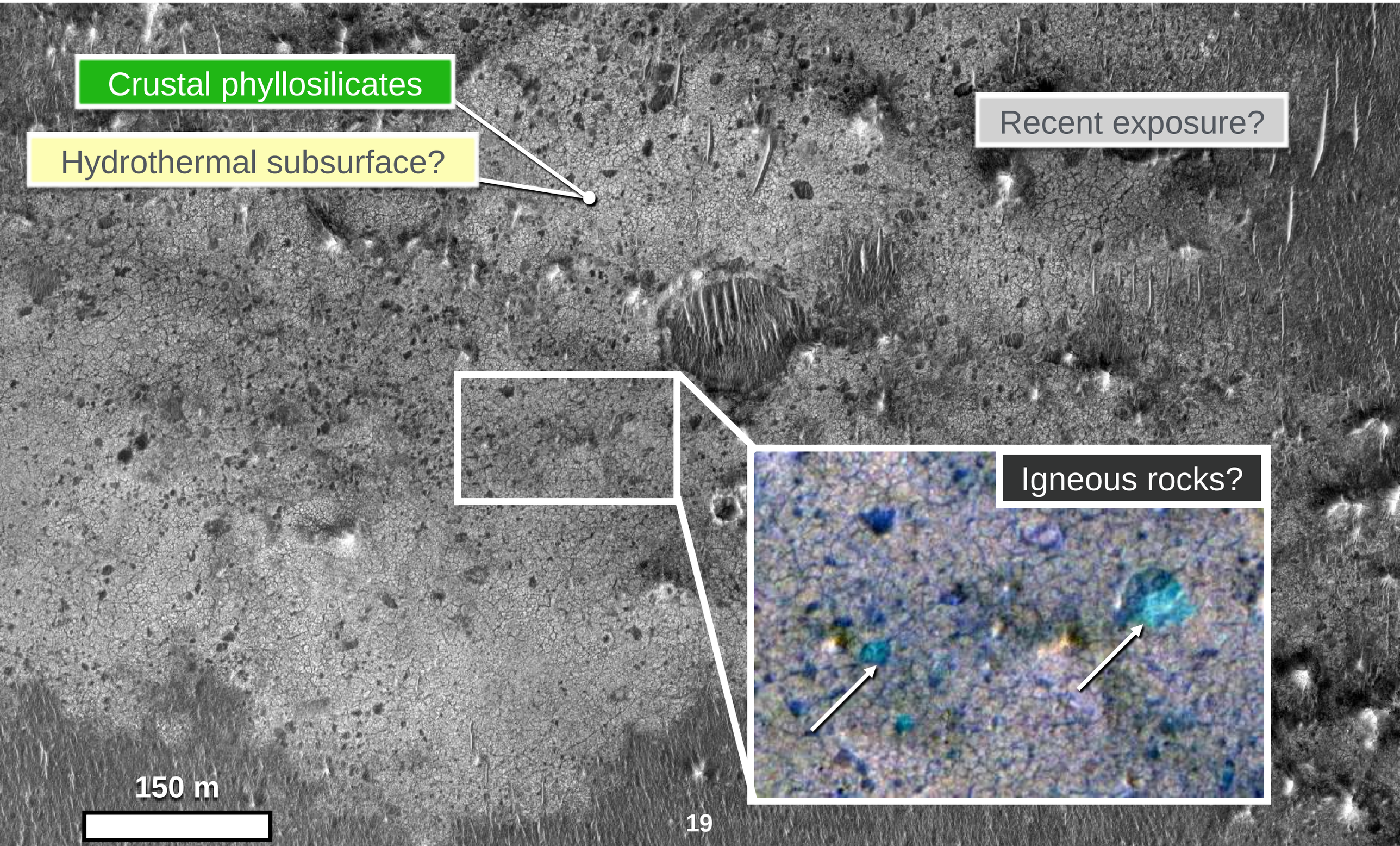
from Schultz et al. 2014

RED: D2300, GREEN: LCPINDEX2, BLUE: BD1900



ROI #1: Noachian crustal clays & LCP

RANK: 3/3



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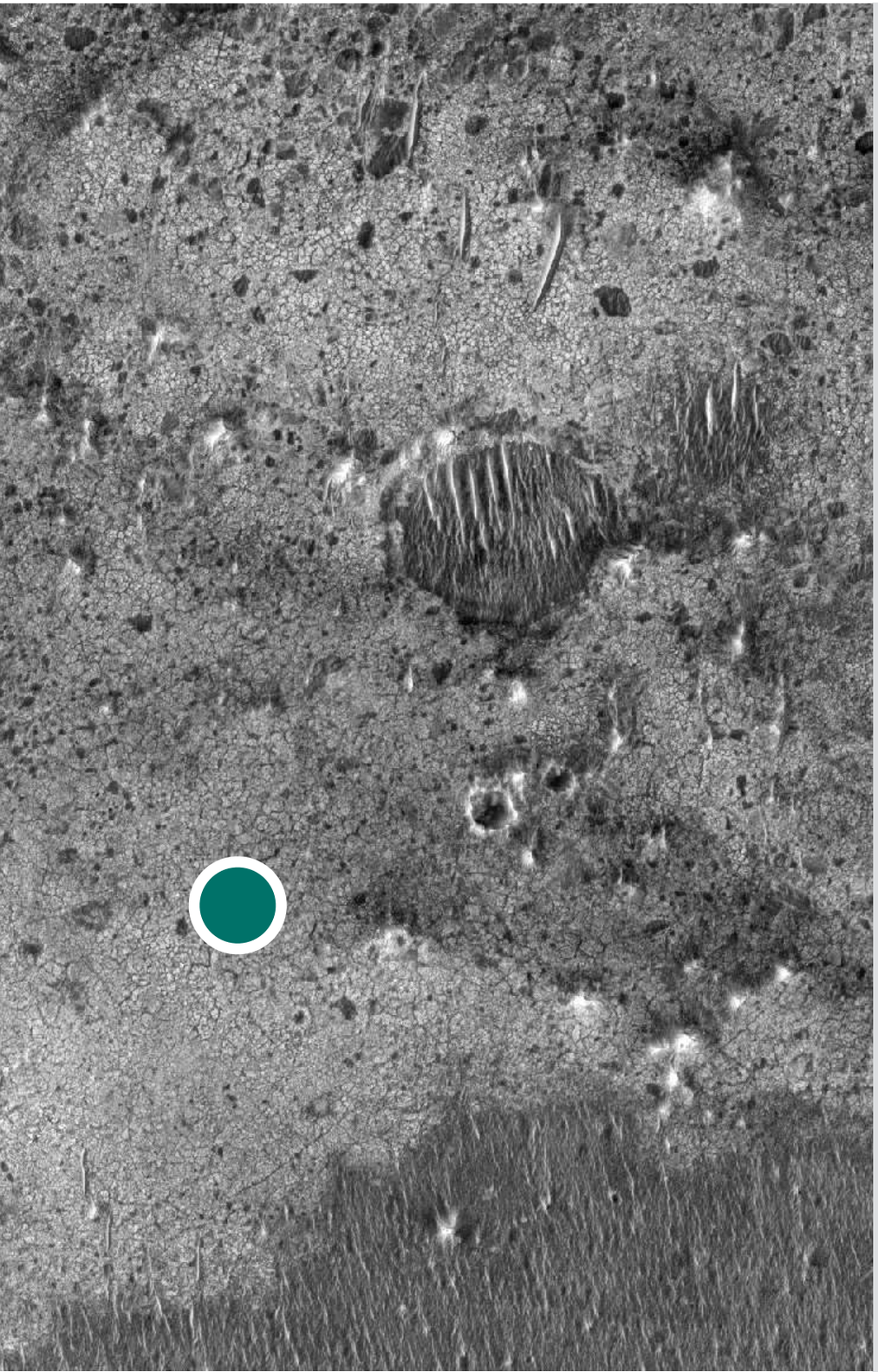
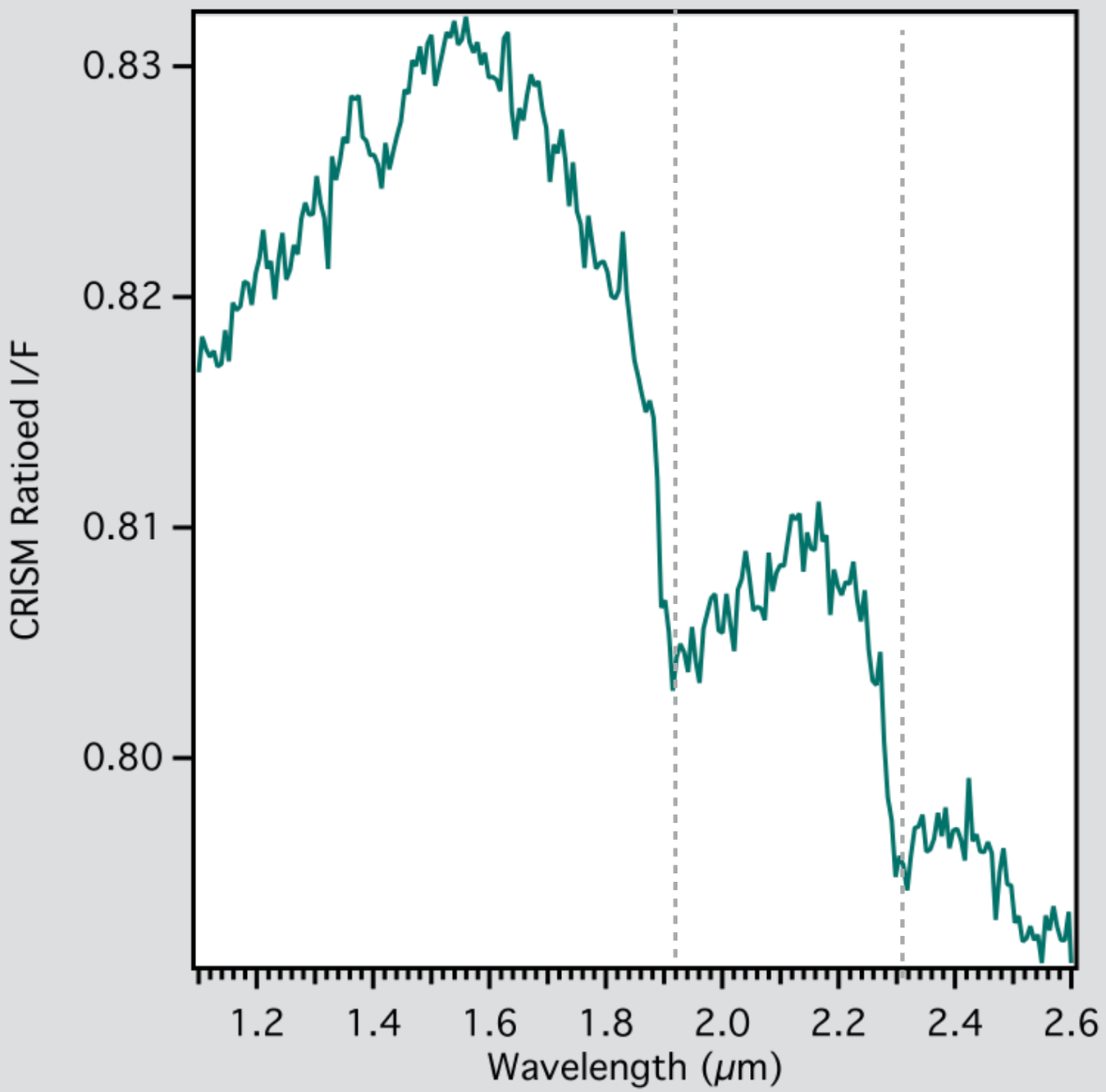




ROI #1: Noachian crustal clays & LCP

RANK: 3/3

A: Geologic history

Crustal clays *and unaltered rocks from* ***mid-Noachian crust*** *demonstrate pervasive water-rock interaction, possibly in a hydrothermal subsurface environment.*

B: *In situ* astrobiology

Excavation of potential subsurface biosphere.
Quenched impactites can preserve biomarkers in amorphous glass.

C: Caching priorities

1. *Altered and unaltered Noachian crustal material.*
2. *Pristine impact products.*
3. *Diversity of clasts within ejecta.*

ROI #1: Noachian crustal clays & LCP

RANK: 3/3

What is the Noachian crust made of? When and to what extent was it altered?

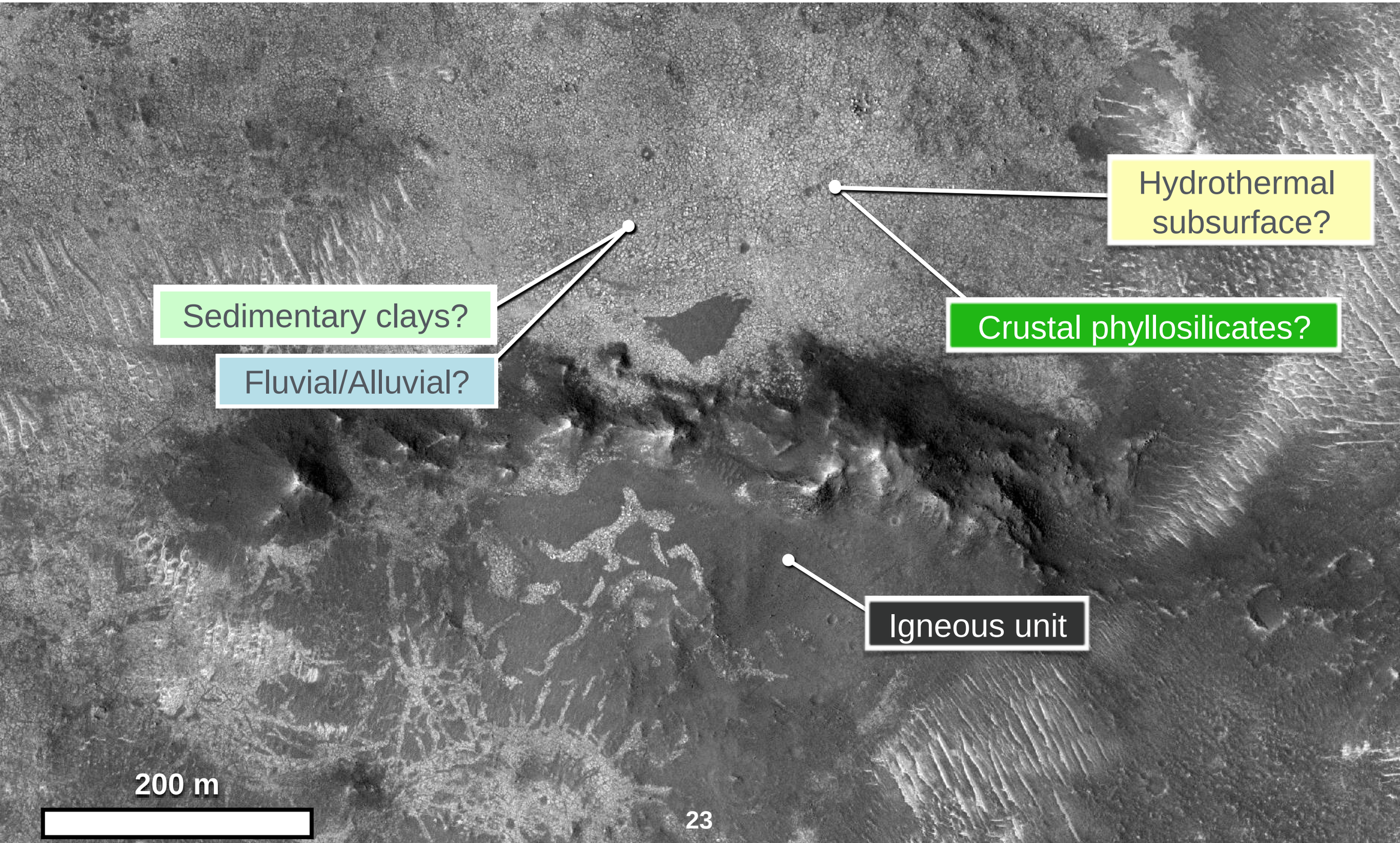
Mastcam-Z SuperCam PIXL MAHLI SHERLOC

Do the clays in the ejecta represent excavated subsurface material (Ehlmann et al. 2012)? Did any of them form post-impact through hydrothermalism (Tornabene et al. 2013)?

Mastcam-Z SuperCam PIXL

ROI #2: Trough fill clays & Syrtis lavas

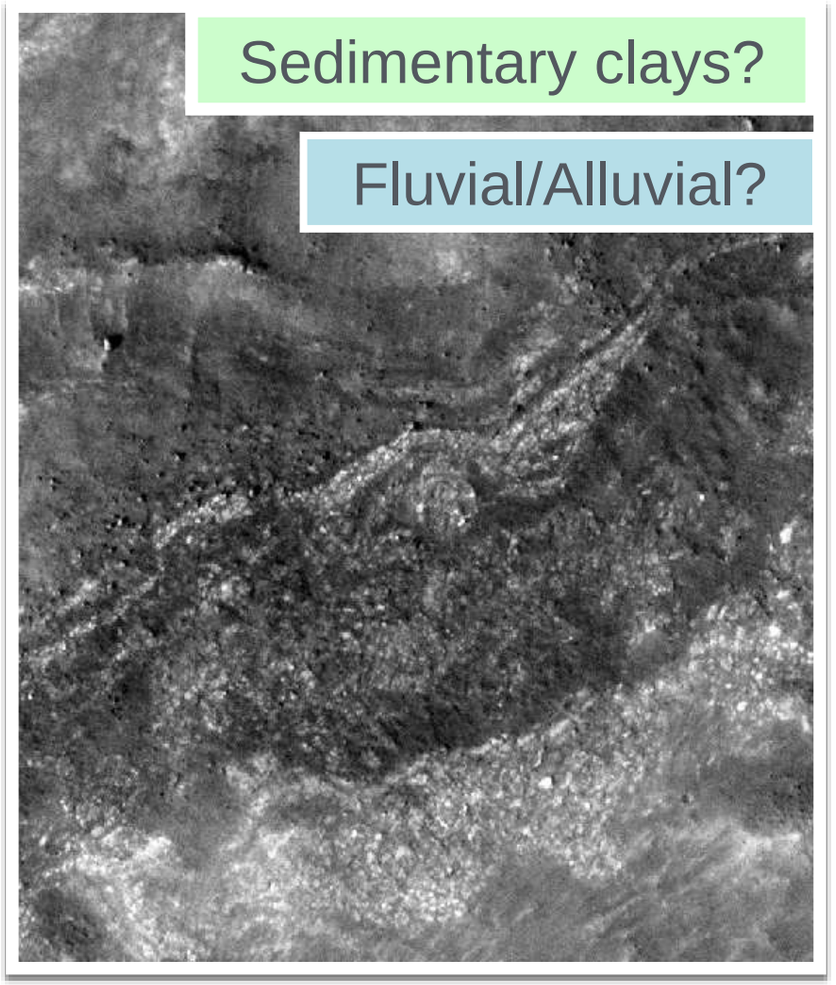
RANK: 2/3

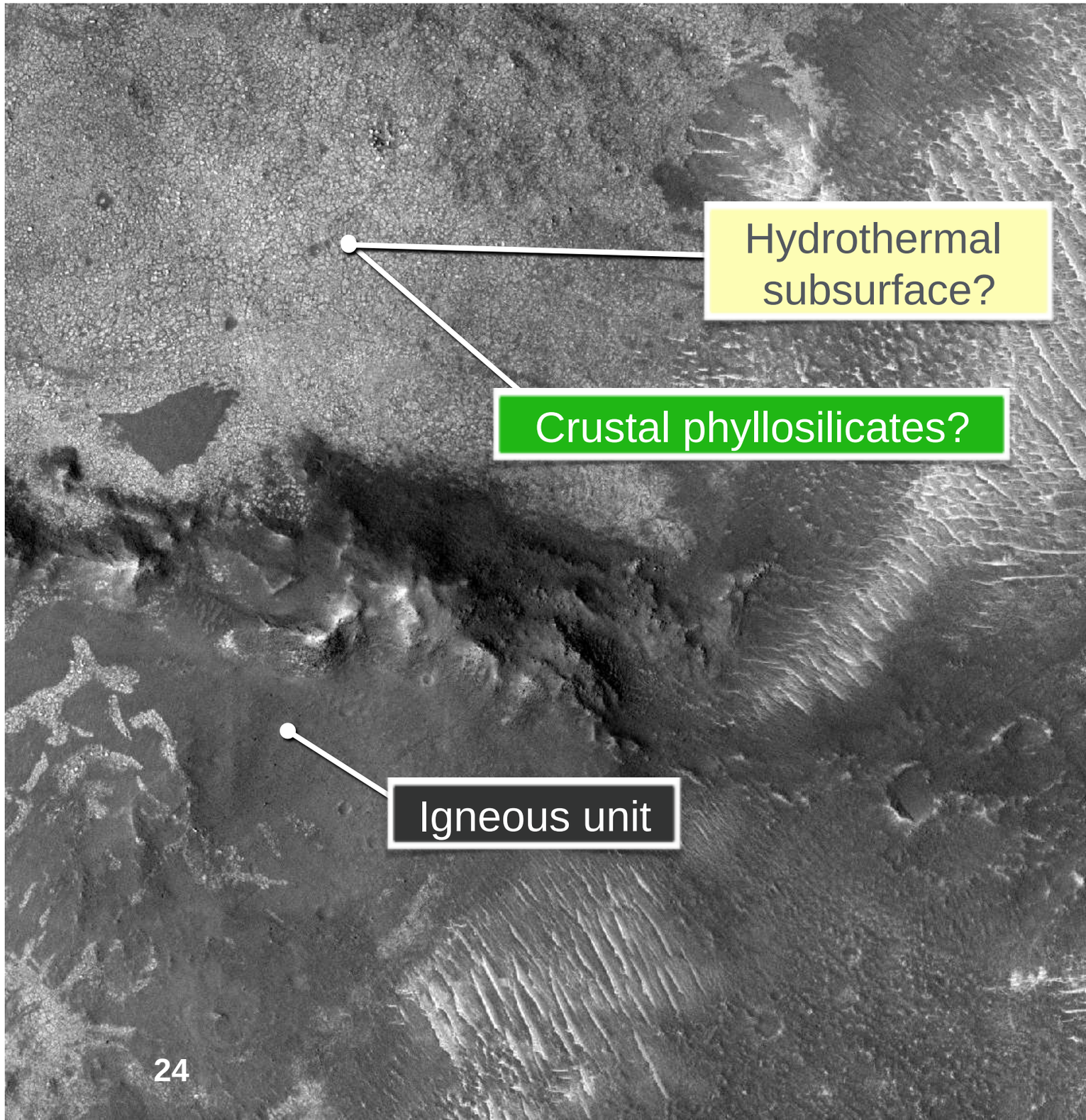


ROI #2: Trough fill clays & Syrtis lavas

RANK: 2/3

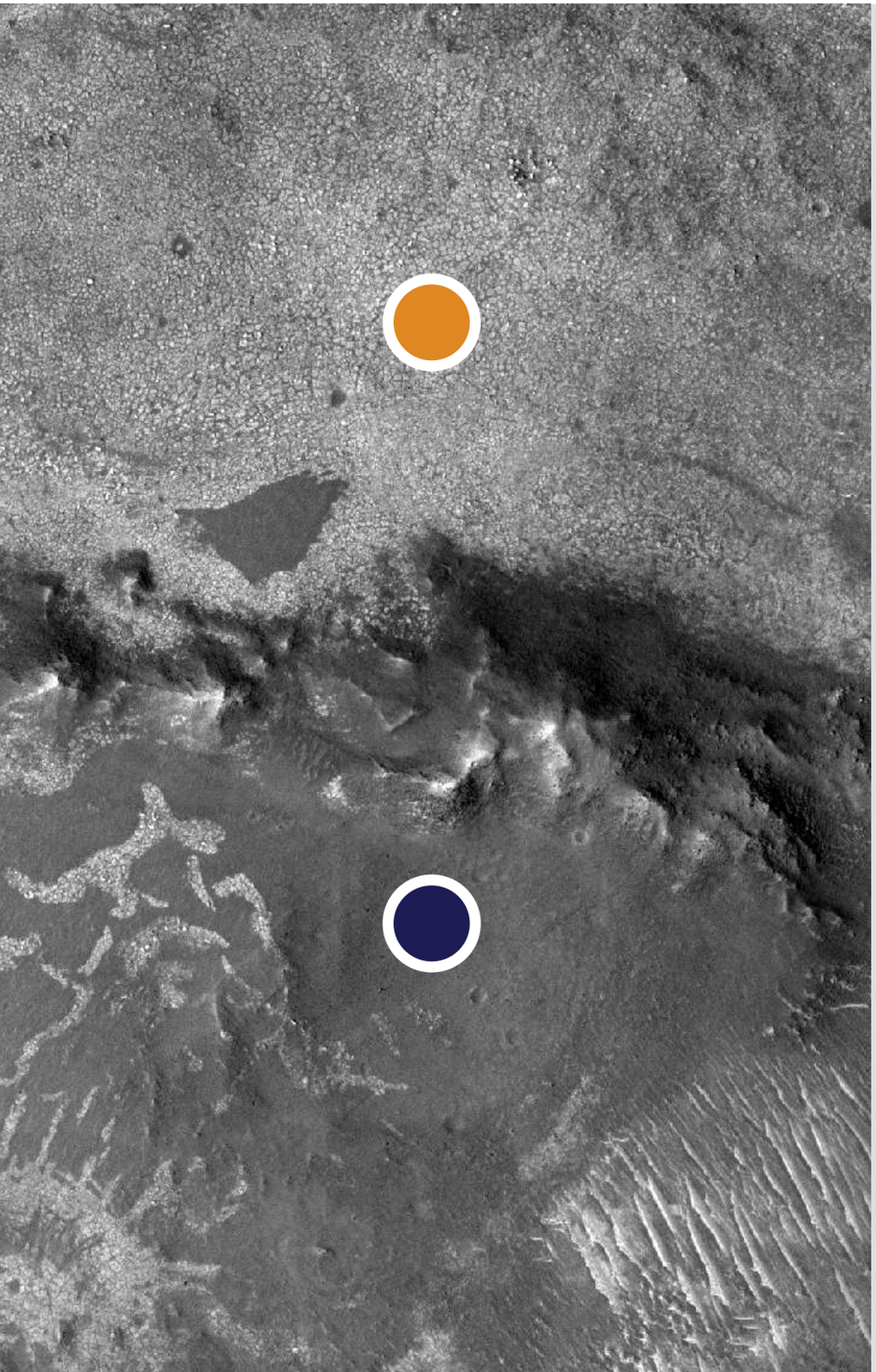
same unit to the North:

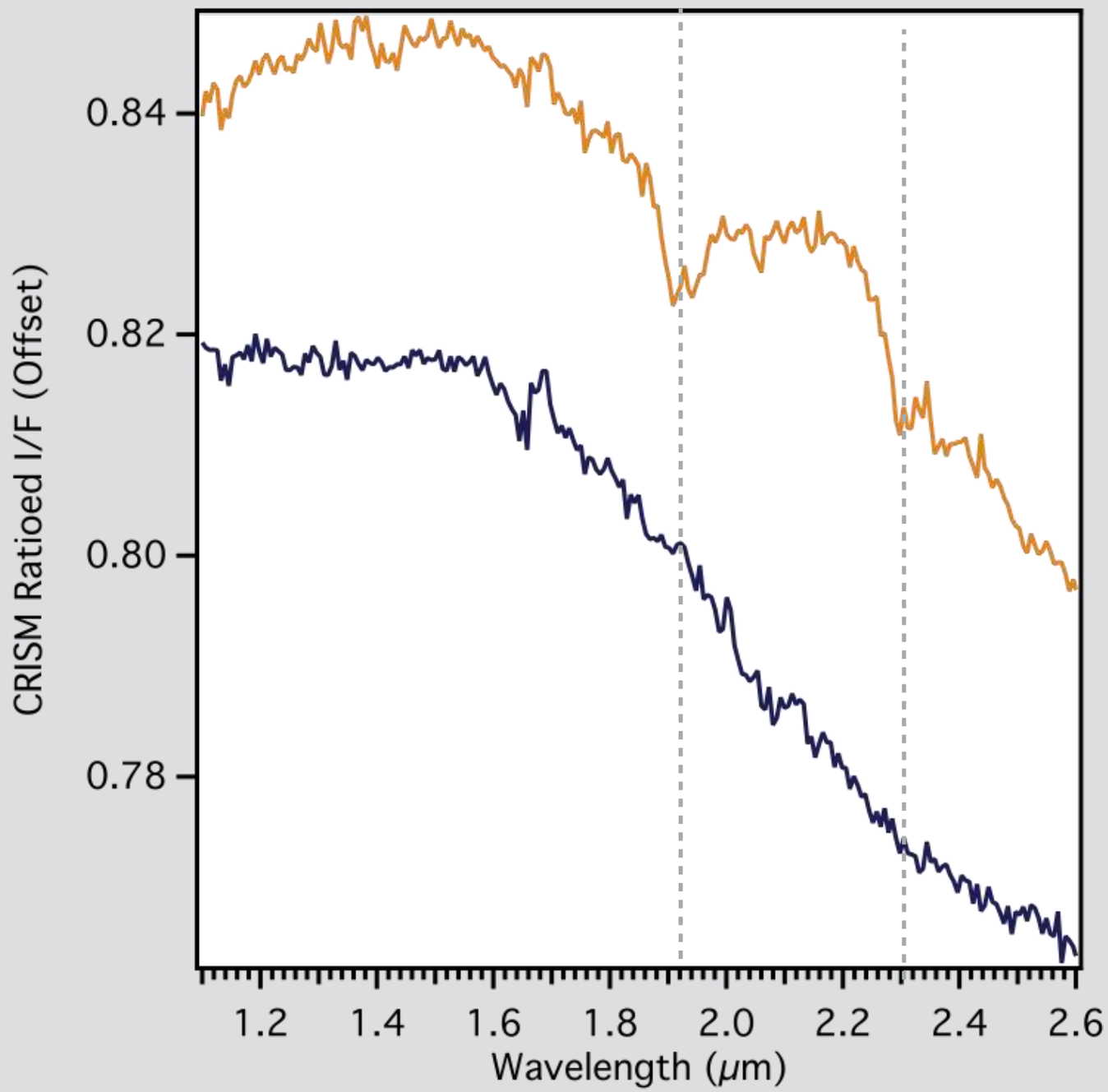




ROI #2: Trough fill clays & Syrtis lavas

RANK: 2/3





ROI #2: Trough fill clays & Syrtis lavas

RANK: 2/3

A: Geologic history

*Trough-fill material contains **abundant clays** and was possibly deposited in a **sedimentary environment** as indicated by layering.*

B: *In situ* astrobiology

Clay-rich rocks are common hosts of organic molecules, especially if the trough fill represents a fluvial/alluvial deposit.

C: Caching priorities

1. Clay-rich trough fill material, especially where found in layered units.
2. Syrtis lavas (textural/compositional endmembers, and chill margins).

D: Human exploration

Buried lava tubes in the Syrtis flows could be found by RIMFAX.

ROI #2: Trough fill clays & Syrtis lavas

RANK: 2/3

Were the trough fill clays deposited in a sedimentary environment? Are they detrital or authigenic?

Mastcam-Z SuperCam RIMFAX PIXL

Do the clays contain preserved organic matter?

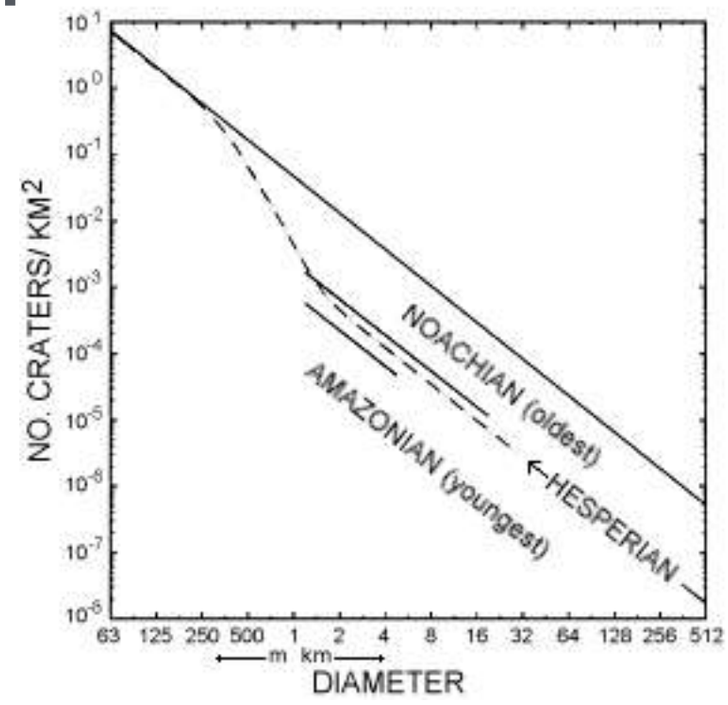
SuperCam SHERLOC

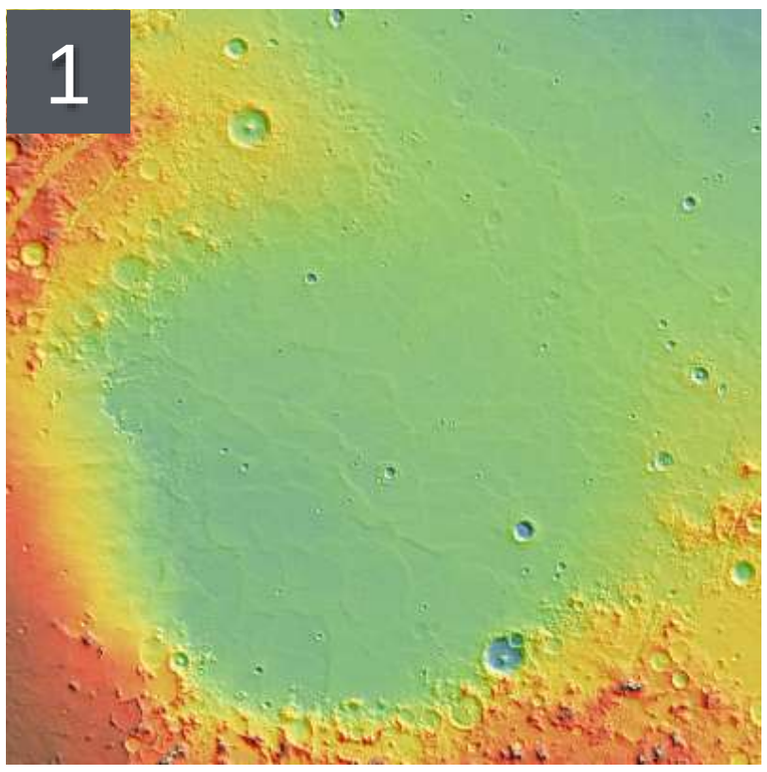
Chronostratigraphy at the Trough

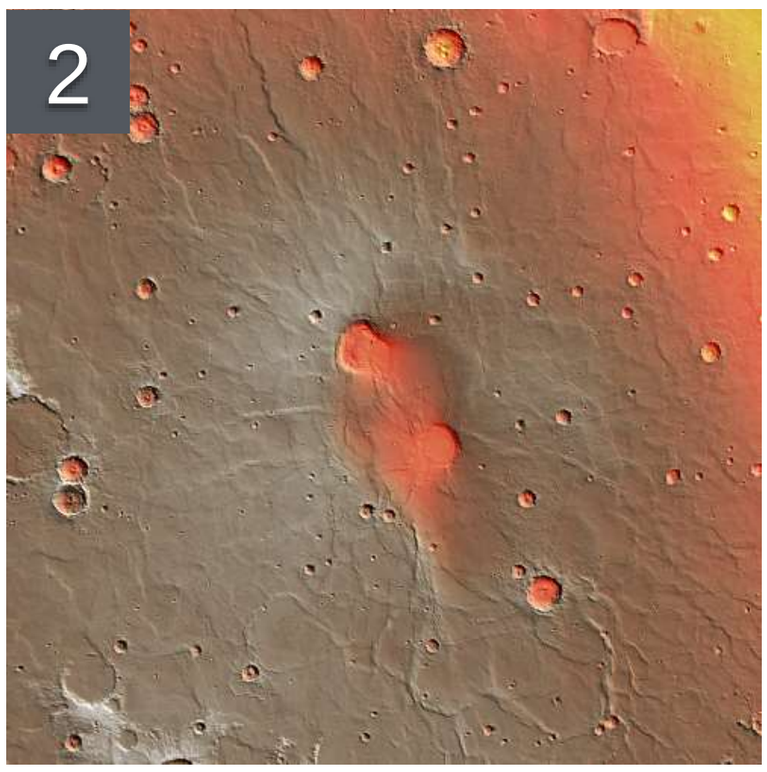
Within the ellipse at Nili Trough there is the potential to place absolute ages on:

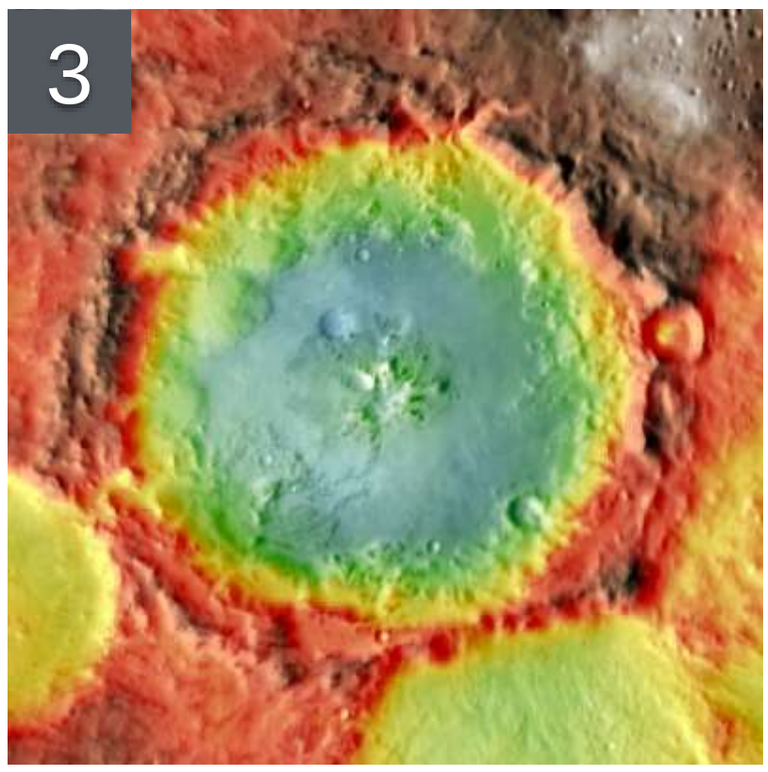
1. Isidis impact
2. Syrtis major lavas
3. Hargraves impact

with returned samples.









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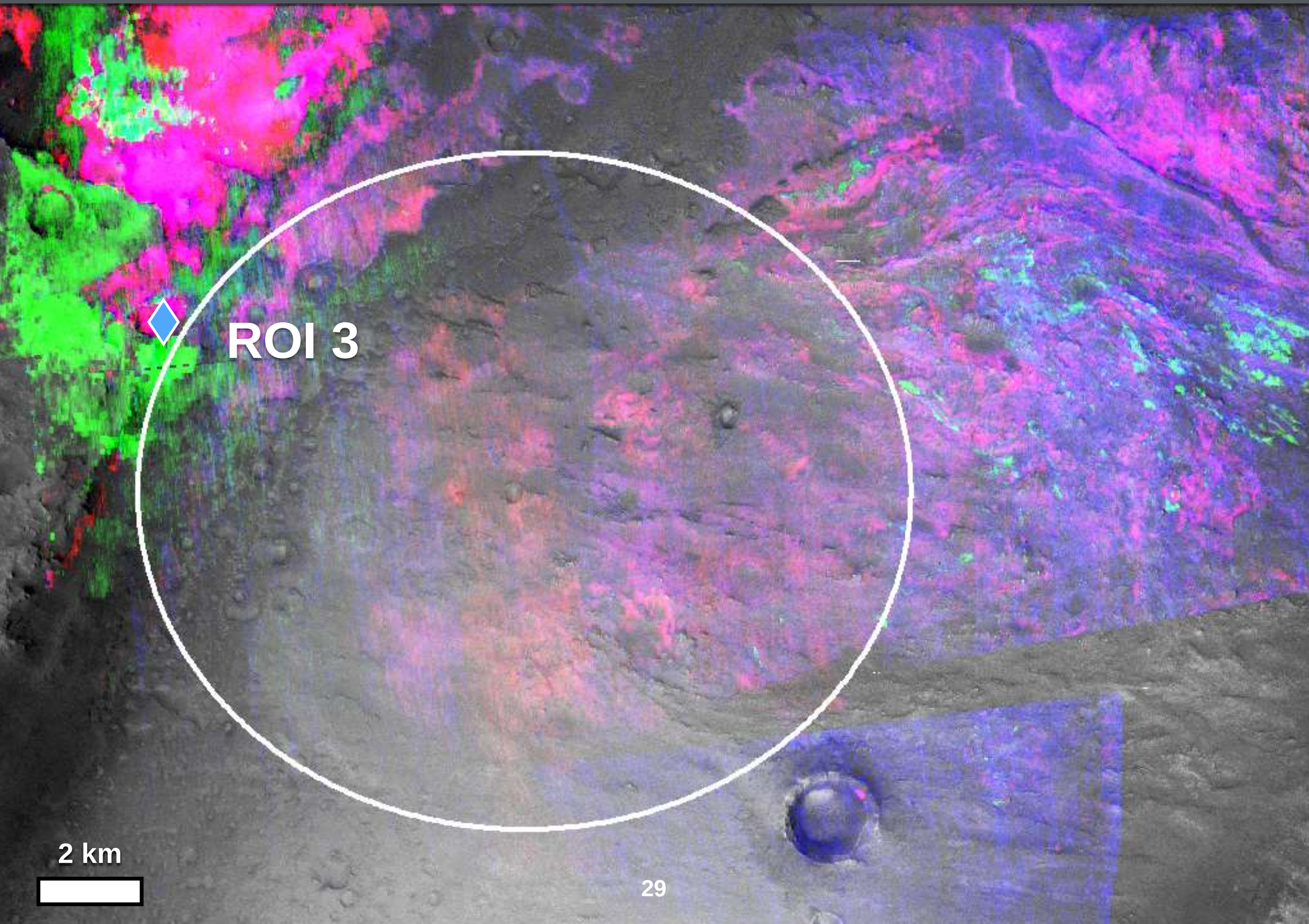
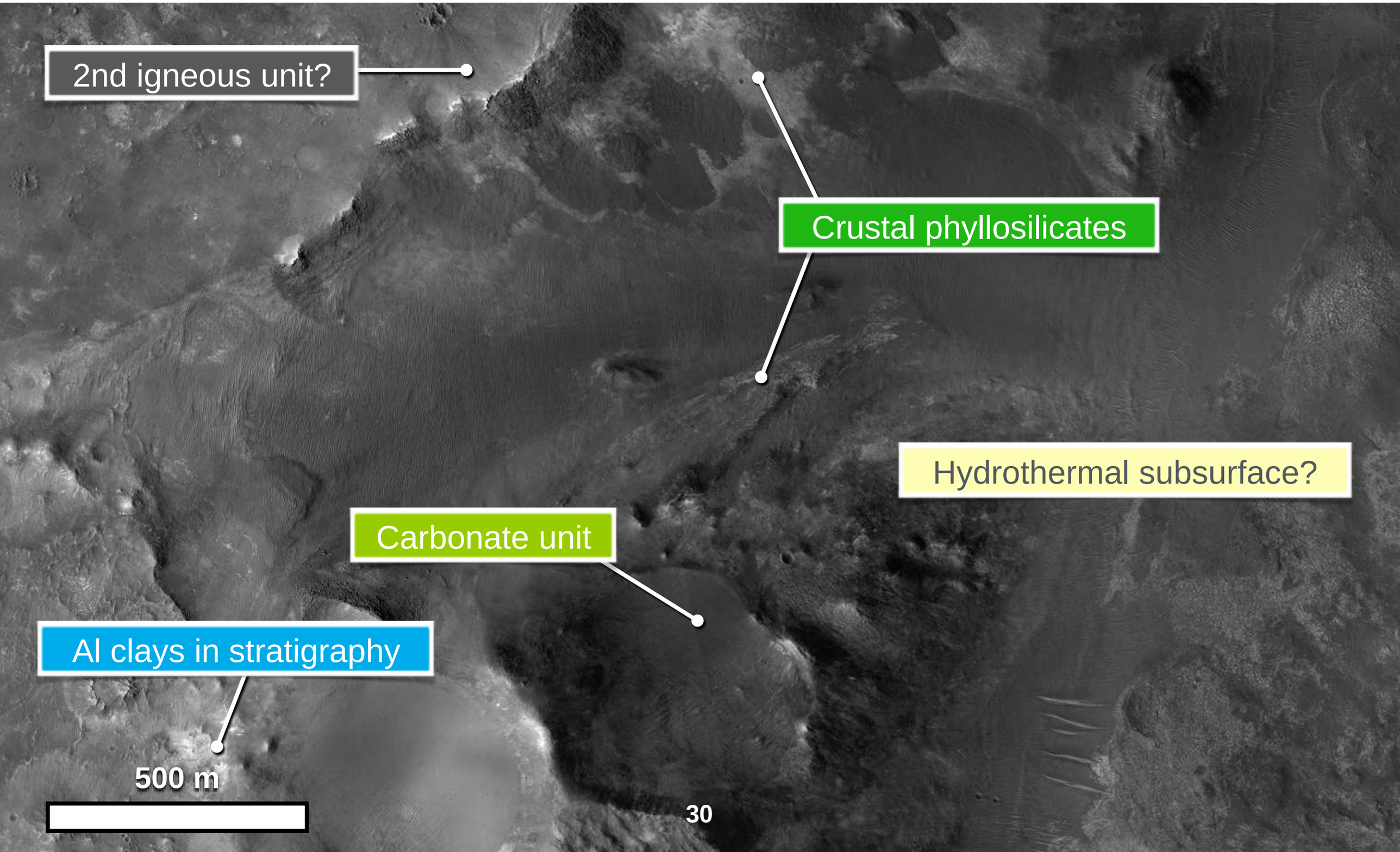


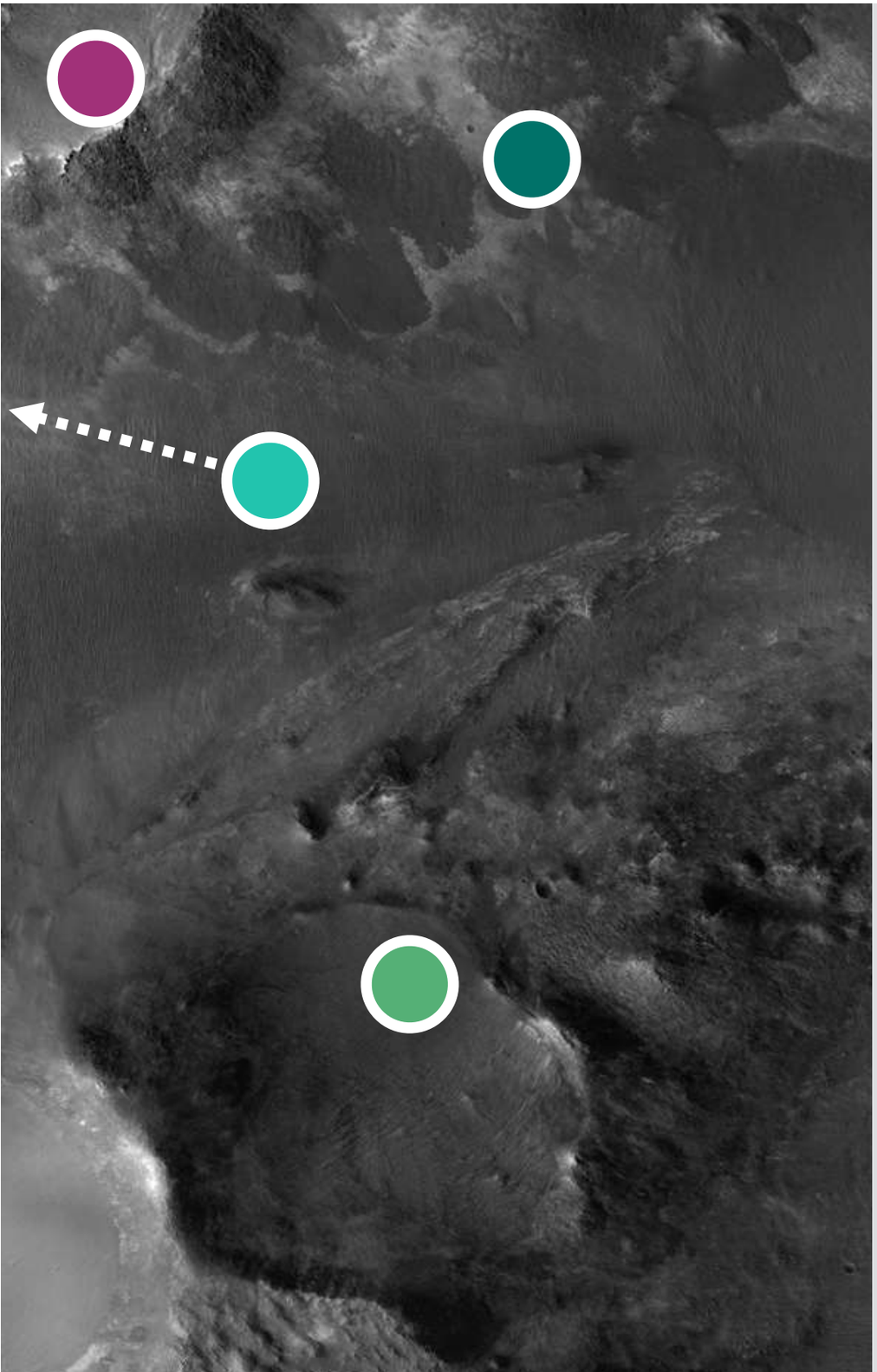
ROI #3: Olivine-clay unit

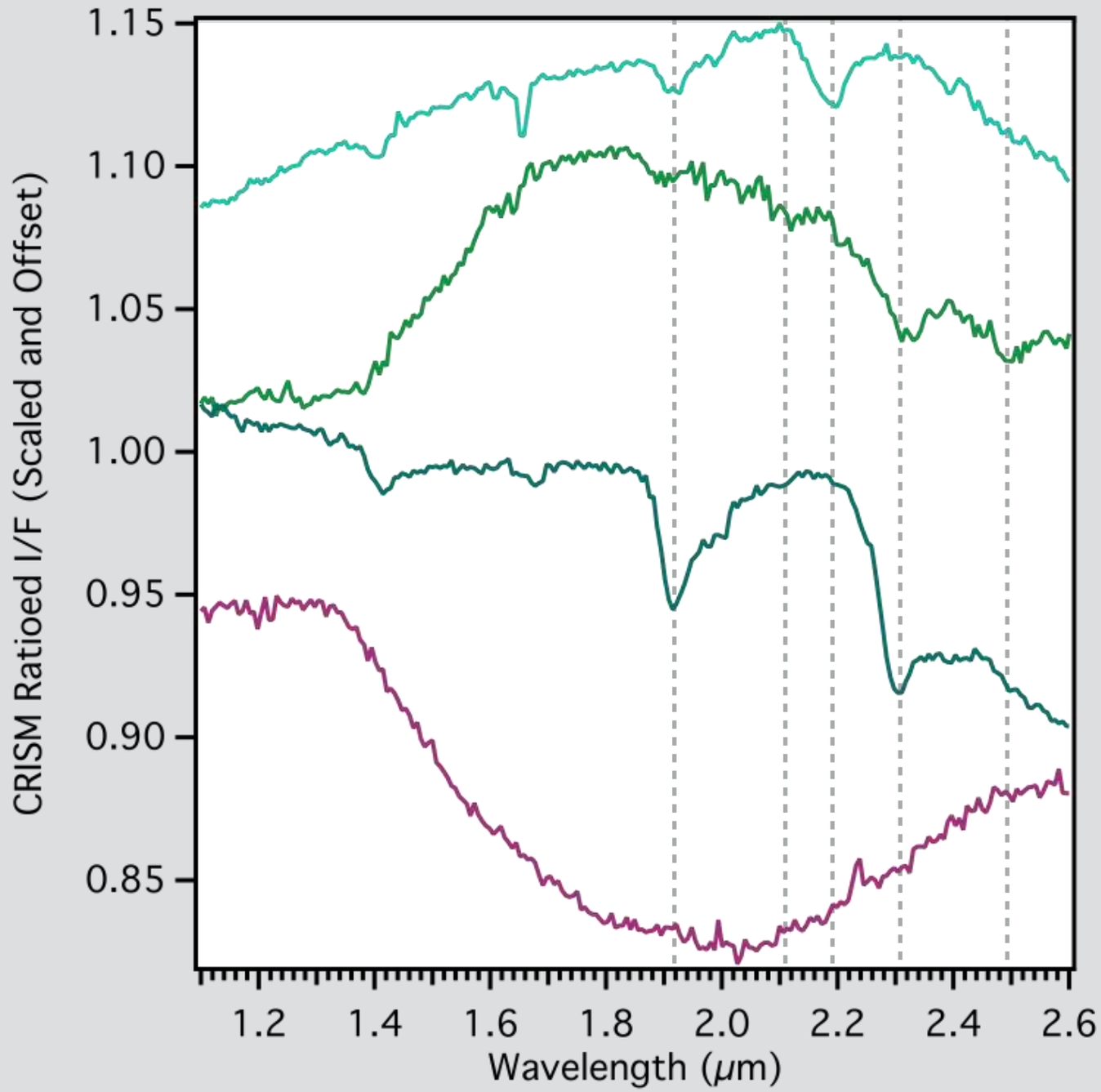
RANK: 1/3



ROI #3: Olivine-clay unit

RANK: 1/3





ROI #3: Olivine-clay unit

RANK: 1/3

A: Geologic history

Unique and diverse mineralogy from altered olivine unit, information about subsurface-water-atmosphere interactions and environments.

B: *In situ* astrobiology

Hydrothermal systems are habitable environments with abundant energy sources and nutrients; biosignatures may be preserved within clays and carbonates.

C: Caching priorities

1. Olivine-clay unit, sampling full mineralogical diversity (esp. carbonate).
2. LCP-rich Noachian crust, Al clays.

ROI #3: Olivine-clay unit

RANK: 1/3

Is the olivine-rich unit volcanic in nature (Hoefen et al. 2003; Hamilton and Christensen 2005; Tornabene et al. 2008) or impact melt (Mustard et al. 2007, 2009)?

SuperCam RIMFAX PIXL MAHLI

Does the olivine-rich unit represent a serpentinizing system (Brown et al. 2010; Viviano-Beck et al. 2013)?

Mastcam-Z SuperCam PIXL MAHLI SHERLOC

Threshold Geological Criteria

• Presence of subaqueous sediments or hydrothermal sediments (equal 1st priority)

OR

✓ Hydrothermally altered rocks or low-T fluid-altered rocks (equal 2nd priority)

✓ Presence of minerals indicative of aqueous phases (e.g., phyllosilicates, carbonates, sulfates, etc.) in outcrop

✓ Noachian/Early Hesperian age based on stratigraphic relations and/or crater counts

✓ Access to unaltered igneous rocks as float

✓ Not a Special Region

Potential Qualifying Geological Criteria

• Morphological criteria for standing bodies of water and/or fluvial activity (deltaic deposits, shorelines, etc.).

✓ Assemblages of secondary minerals of any age.

• Presence of former water ice, glacial activity or its deposits.

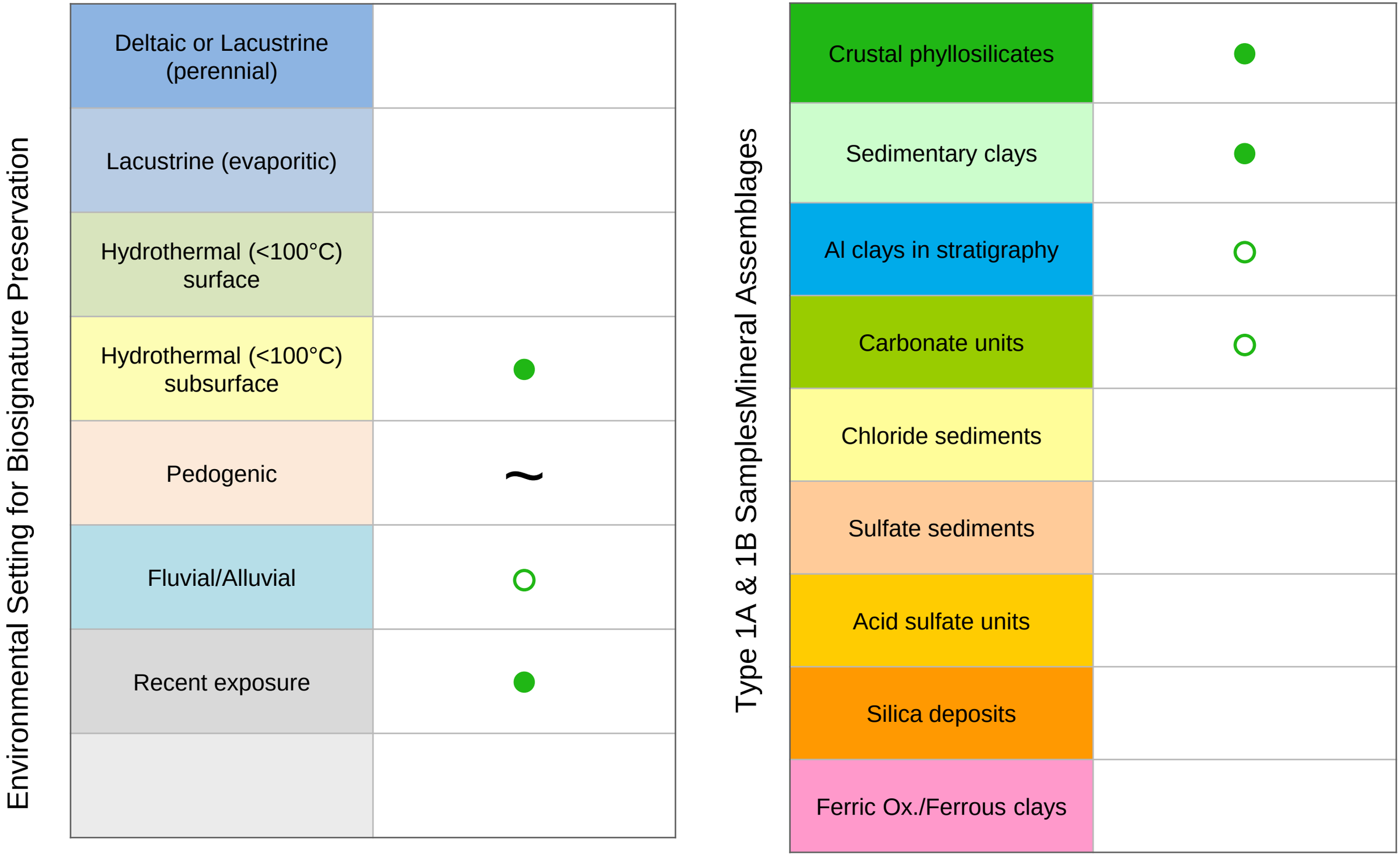
✓ Igneous rocks of Noachian age, of known stratigraphic relation, better if including exhumed megabreccia.

✓ Volcanic unit of Hesperian or Amazonian age well-defined by crater counts and well-identified by morphology and/or mineralogy.

✓ Probability of samples of opportunity (ejecta breccia, mantle xenoliths, etc.).

• Potential for resources for future human mission

Rubric


Environmental Setting for Biosignature Preservation
Deltaic or Lacustrine (perennial)
Lacustrine (evaporitic)
Hydrothermal (<100°C) surface
Hydrothermal (<100°C) subsurface
Pedogenic
Fluvial/Alluvial
Recent exposure
Type 1A & 1B SamplesMineral Assemblages
Crustal phyllosilicates
Sedimentary clays
Al clays in stratigraphy
Carbonate units
Chloride sediments
Sulfate sediments
Acid sulfate units
Silica deposits
Ferric Ox./Ferrous clays
In-ellipse
Go-to (<10 km)

Rubric

Type 2 Samples: Igneous

Igneous unit (e.g, lava flow, pyroclastic, intrusive)	●
2nd Igneous unit	○

Context: Martian History Sampled, Timing Constraints

Pre- or Early-Noachian Megabreccia	~
Oldest stratigraphic constraint	MN
Youngest stratigraphic constraint	EH
Stratigrapy of units well-defined	●
Dateable surface, volcanic (unmodified crater SFD)	●

● In-ellipse ○ Go-to (<10 km)

Nili Fossae Trough summary

- Land-on clays (ancient altered Noachian crust)
- Rich, diverse in-ellipse science
- Multiple habitable environments (layered clays, hydrothermal, ejecta facies)
- Biosignature preservation potential in clays, impact breccias
- Extremely important chronostratigraphy (Hesperian lava, Isidis, Hargraves)
- Diverse mineralogy (carbonate, Fe/Mg clay, Al clay, LCP, ±serpentine)
- Geologic units are distinct, in place with clear stratigraphic relations
- All major targets <10 km from ellipse center

Extra slides

Rubric

Environmental Setting for Biosignature Preservation	
Deltaic or Lacustrine (perennial)	
Lacustrine (evaporitic)	
Hydrothermal (<100°C) surface	~
Hydrothermal (<100°C) subsurface	●
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Fluvial/Alluvial	~
Recent exposure	●

Type 1A & 1B SamplesMineral Assemblages	
Crustal phyllosilicates	●
Sedimentary clays	●
Al clays in stratigraphy	○
Carbonate units	○
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Rubric

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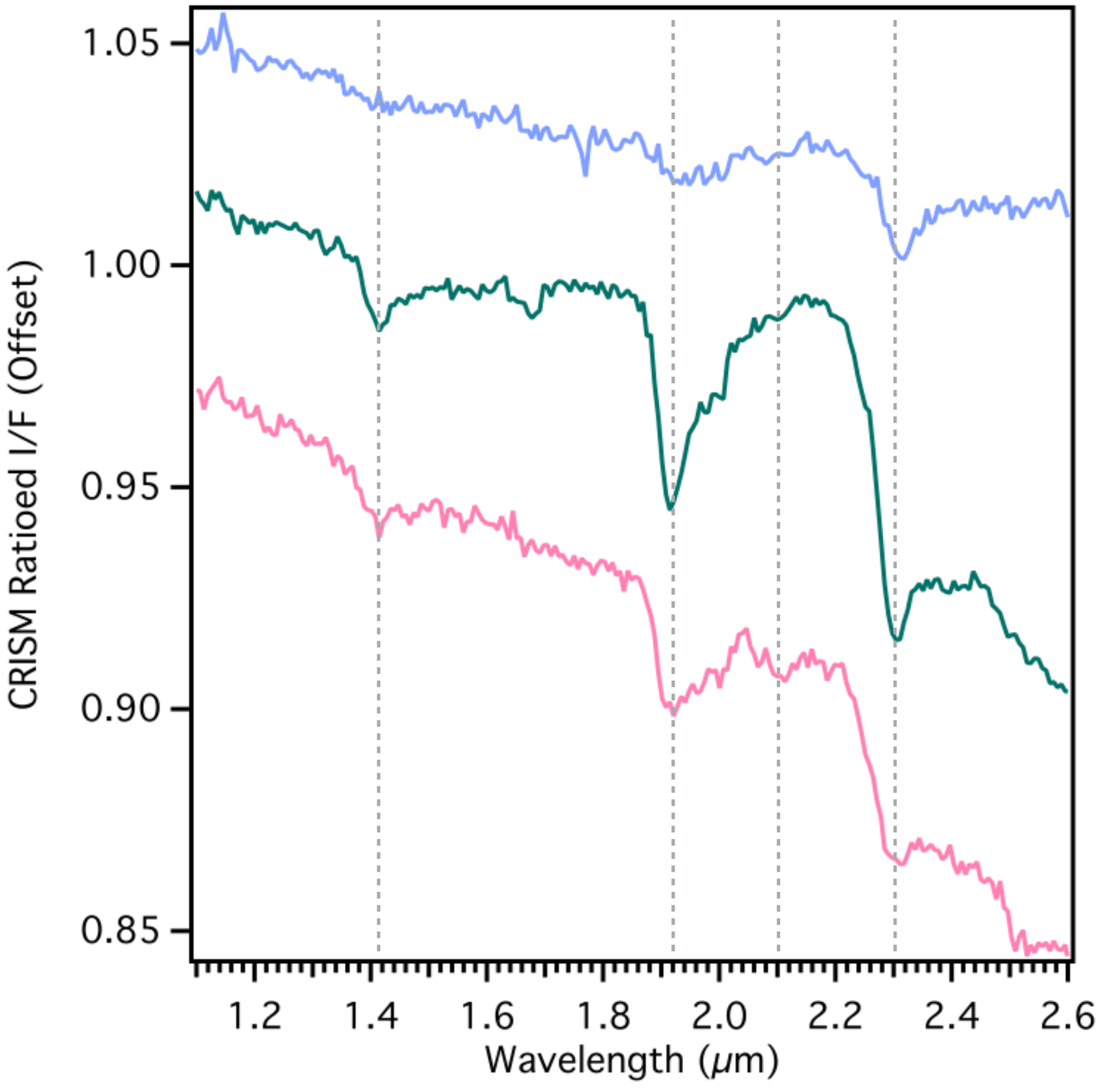
CRISM Ratioed I/F (Offset)
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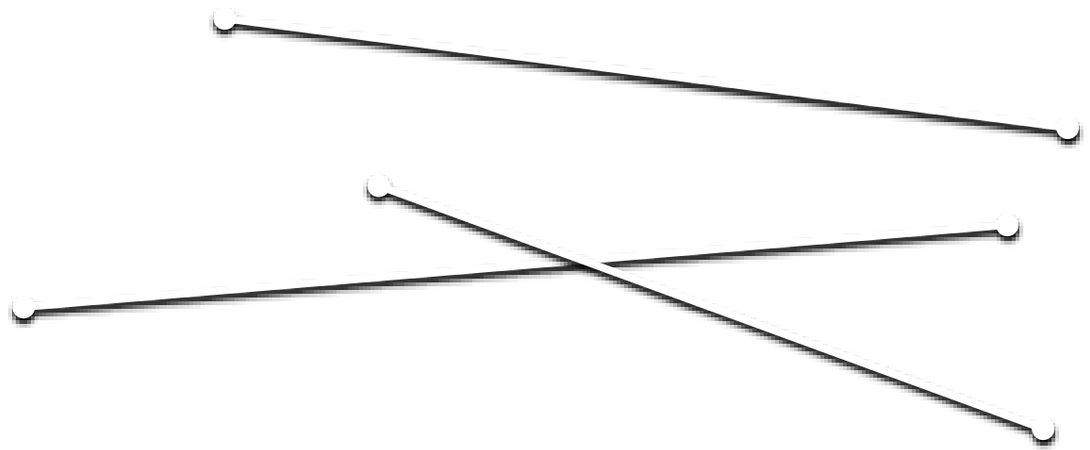
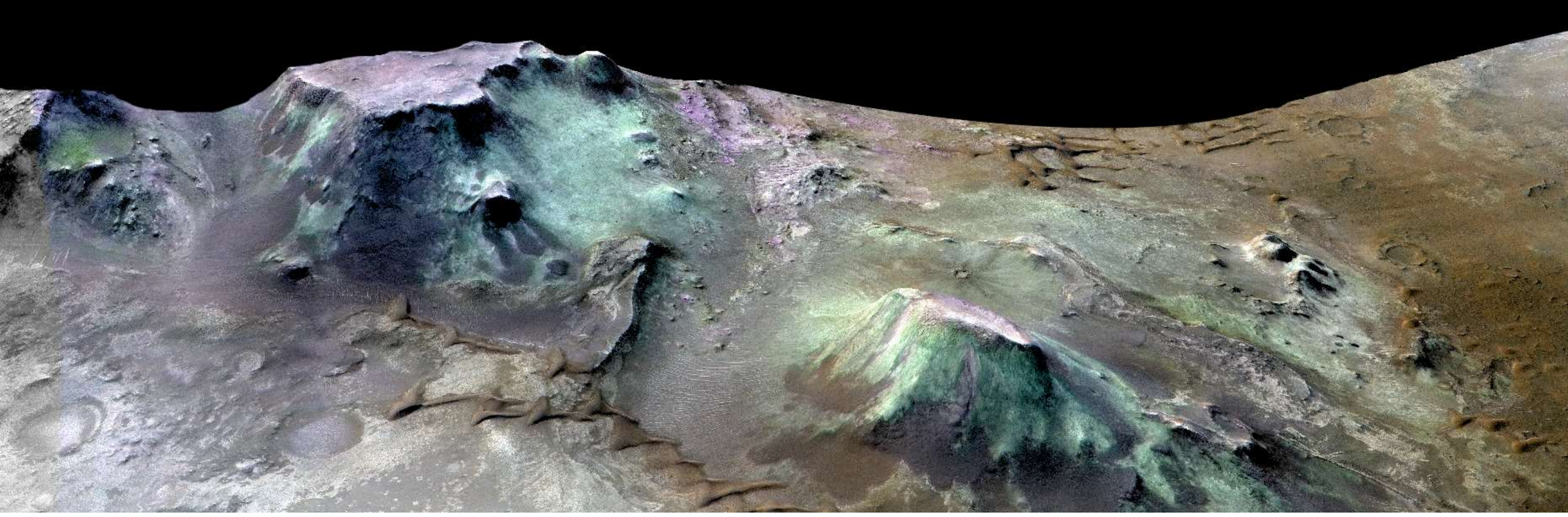
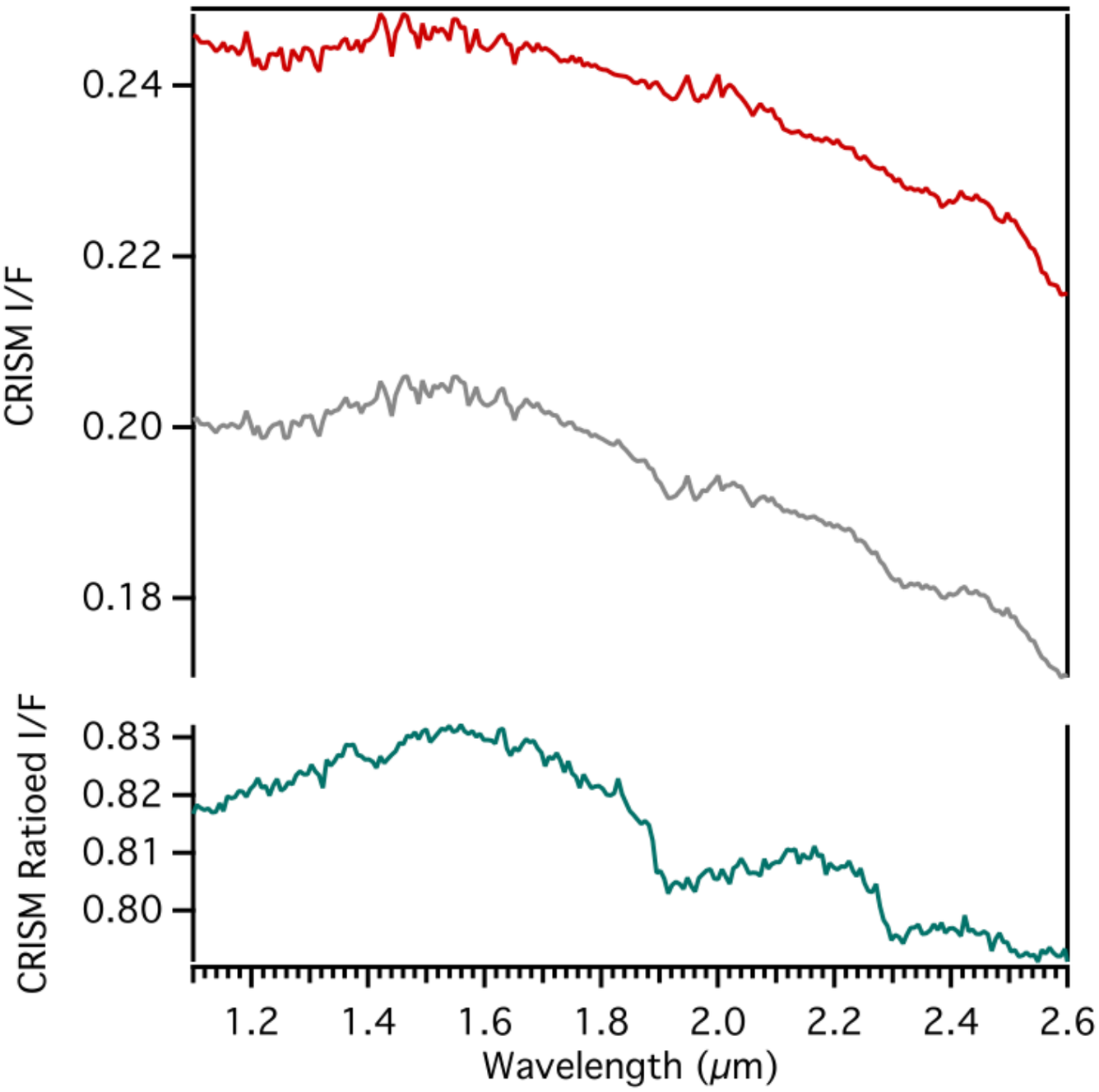
1.00
0.95
0.90
0.85
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Wavelength (μm)

9D44



64D9



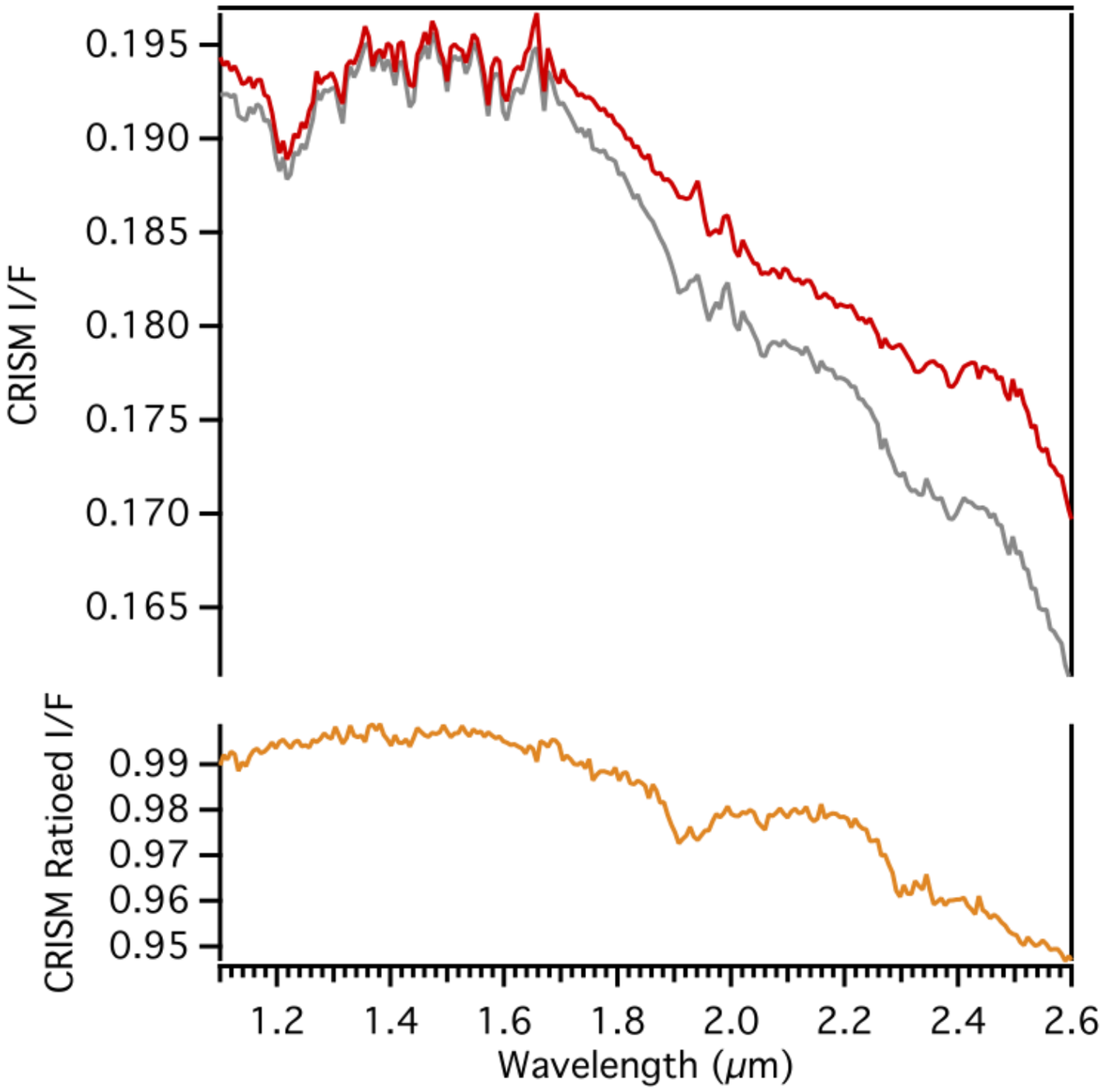


Ejecta clay

OBS: FRT00008530

Numerator: x=337; y=375
Denominator: x=337; y=10

Average: 5x5 pixels



Trough fill clay

OBS: FRT00008530

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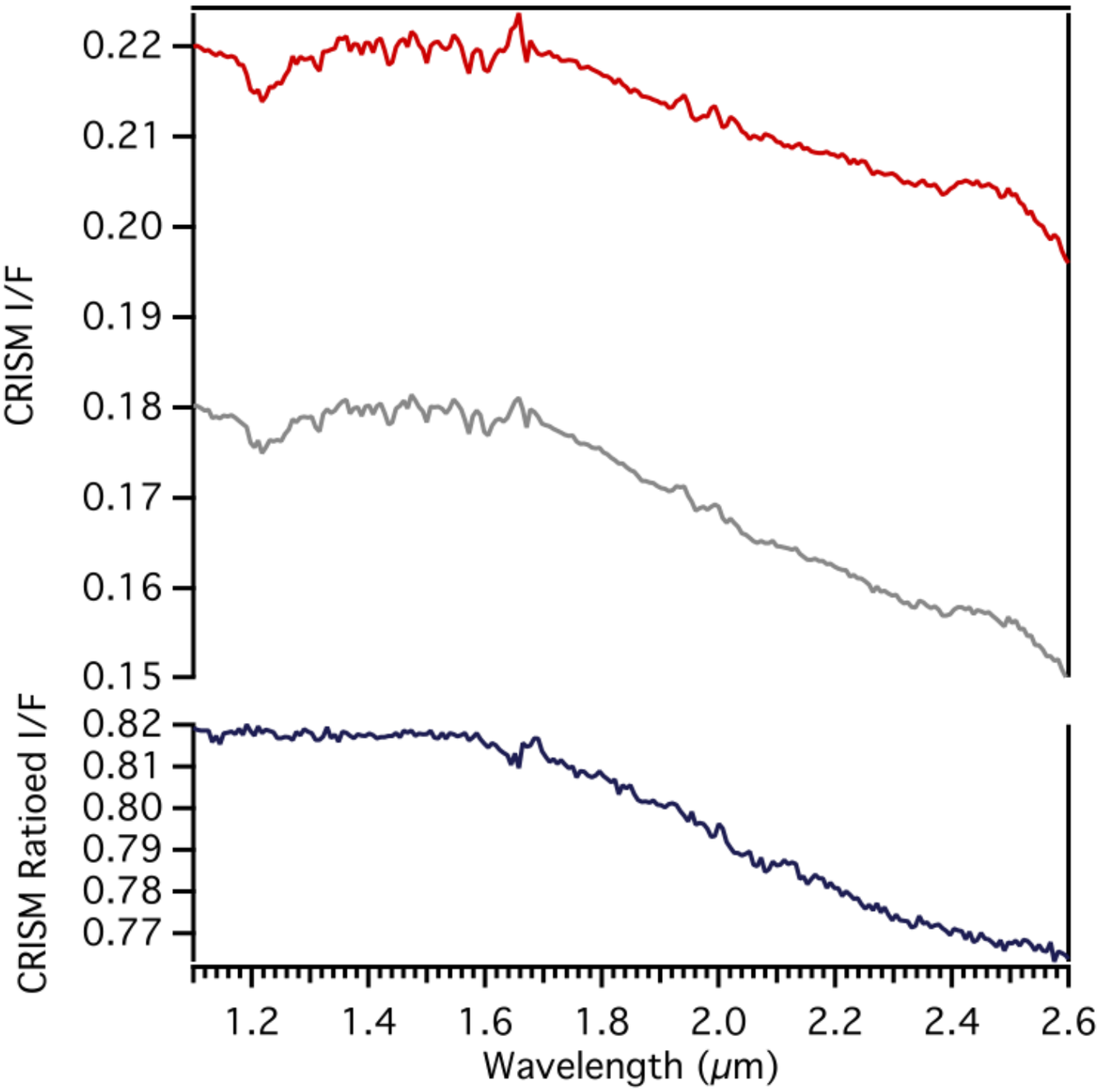
Denominator: x=589; y=291

Average: 5x5 pixels

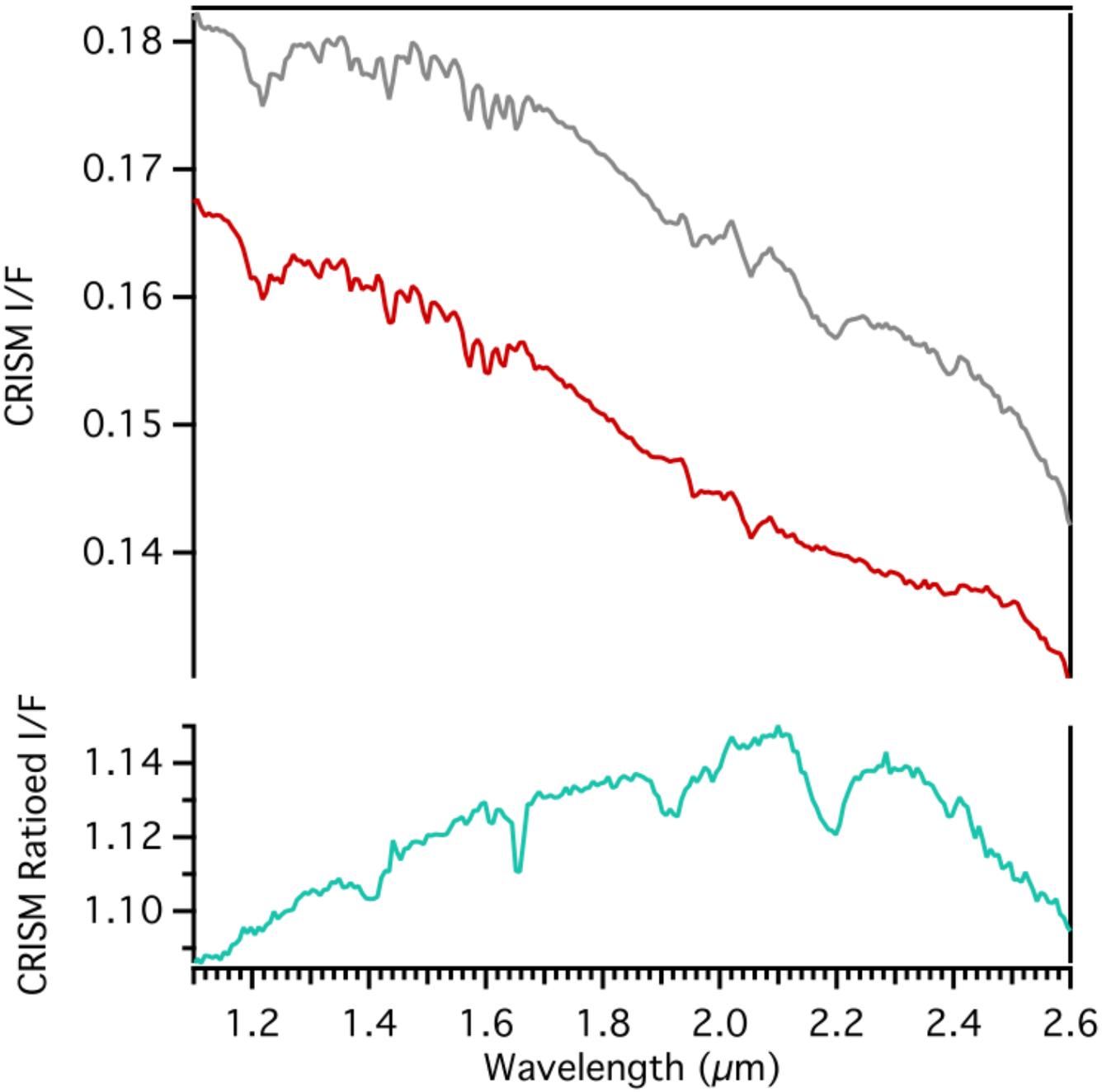


Syrtis lavas

OBS: FRT00008530

Numerator: x=587; y=412
Denominator: x=587; y=91

Average: 5x5 pixels



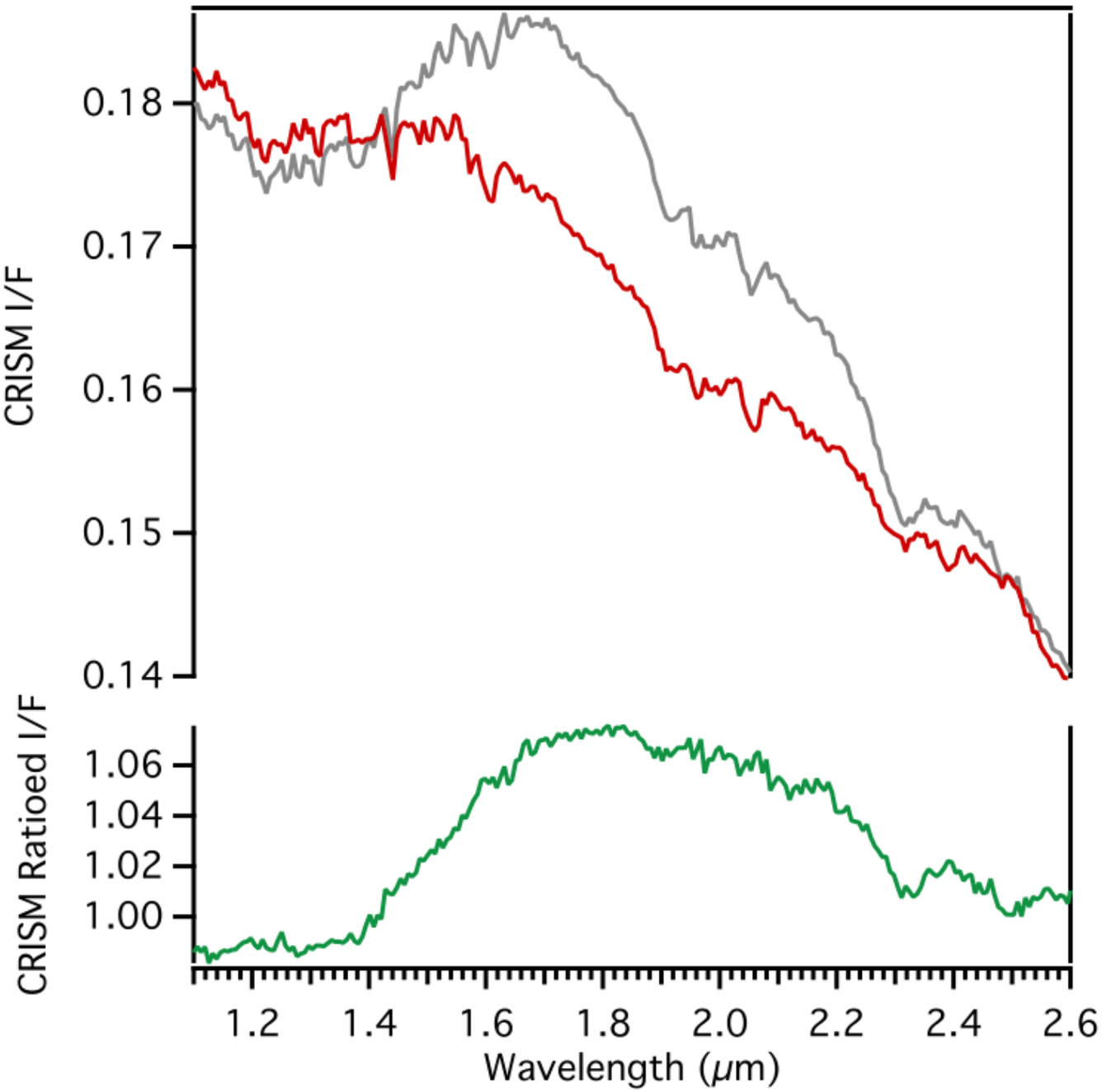
Al clay

OBS: FRT000064D9

Numerator: x=611; y=71

Denominator: x=611; y=91

Average: 5x5 pixels

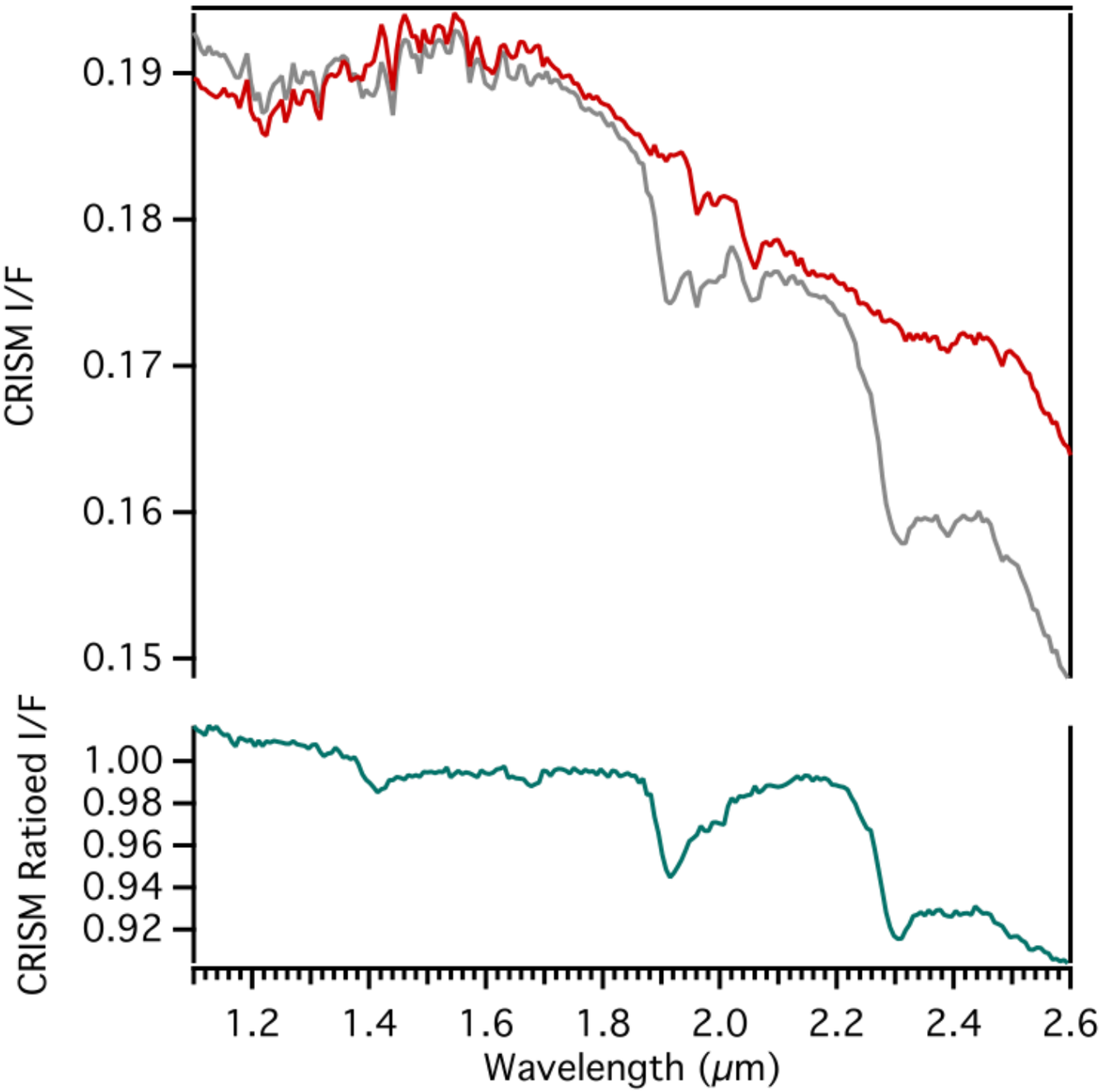


<u>Carbonate</u>

OBS: FRT000064D9

Numerator: x=459; y=7
Denominator: x=459; y=19

Average: 1x1 pixel



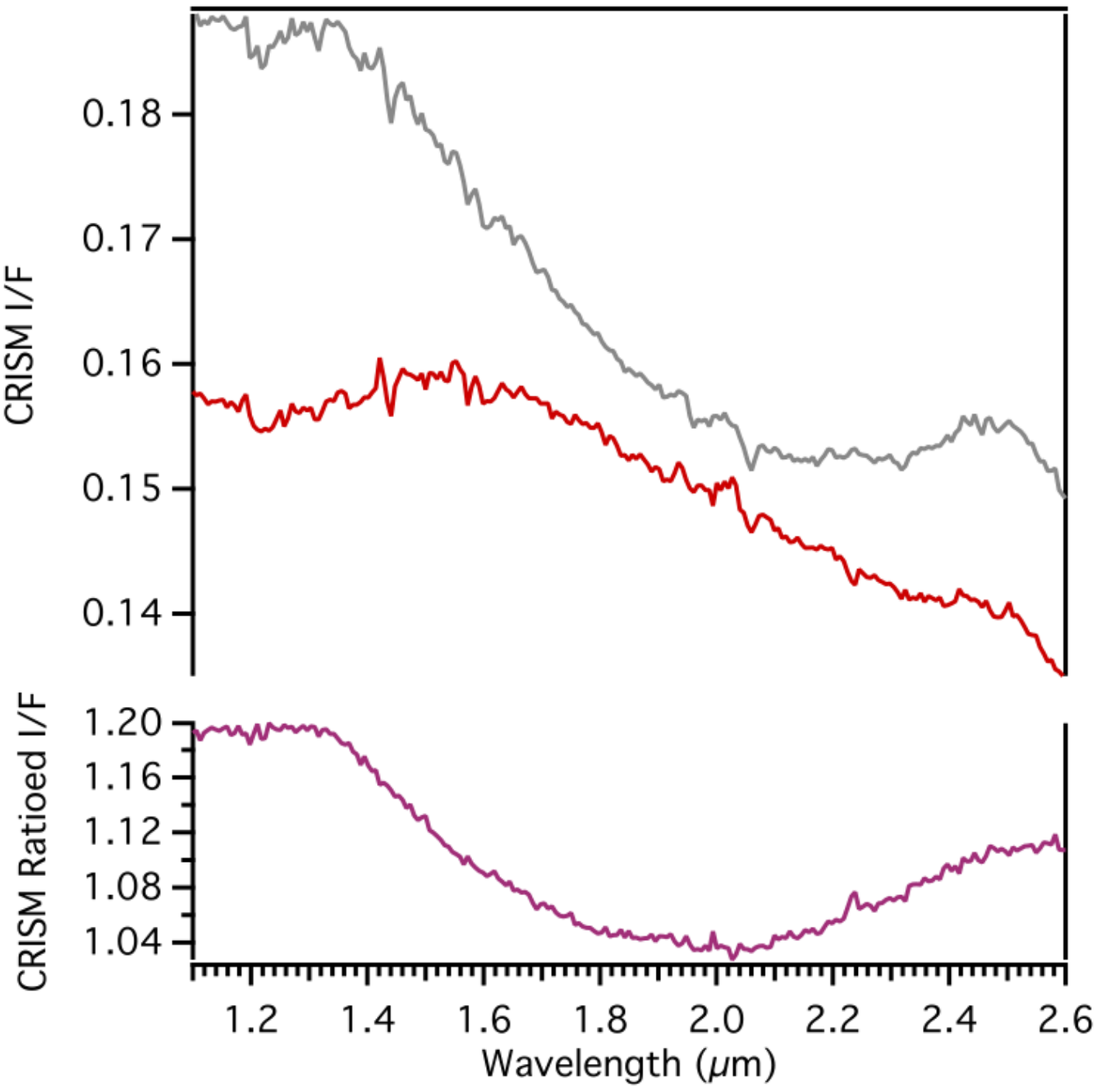
Olivine unit phyllosilicate

OBS: FRT000064D9

Numerator: x=455; y=40

Denominator: x=455; y=412

Average: 5x5 pixels



Low-calcium pyroxene

OBS: FRT000064D9

Numerator: x=495; y=4
Denominator: x=495; y=311

Average: 1x3 pixels